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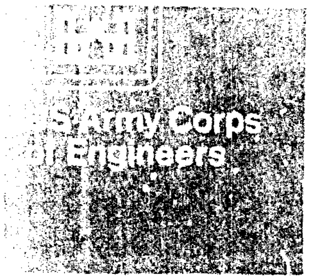

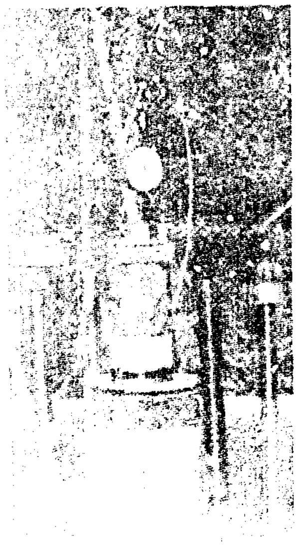

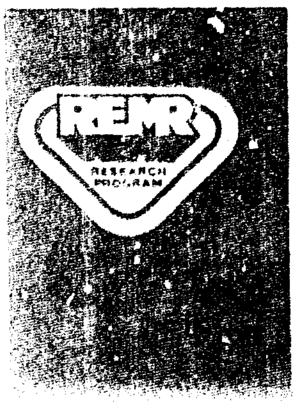

REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-CS-20

EVALUATION OF VINYLESTER RESIN FOR ANCHOR EMBEDMENT IN CONCRETE

by

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Structures Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP — Anchor embedment in concrete with vinylester resin.

BOTTOM — Tensile test on anchor installed under submerged conditions.

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The purpose of this study was to evaluate the load-carrying capacity of anchors embedded in concrete with Hilti's HEA vinylester resin capsules. Anchors installed in vertical drill holes under dry and submerged conditions were tested to determine tensile and shear load capacities.

For the range of parameters in this study (hole condition, embedment length, and test age), results of pullout tests on threaded-rod anchors installed in dry holes were remarkably consistent with an overall average tensile capacity of 105 kips at 0.1-in. displacement and an average ultimate load of approximately 125 kips. In comparison, results of pullout tests on anchors installed under submerged conditions were relatively erratic with an overall average tensile capacity of 36 kips at 0.1-in. displacement and an average ultimate load of 48 kips. Obviously, the tensile load capacity of anchors embedded in

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19. ABSTRACT (Continued).

concrete with vinylester resin capsules is significantly reduced when the anchors are installed under submerged conditions. At a displacement of 0.1 in., the tensile capacity of anchors embedded under submerged conditions was approximately one-third that of similar anchors embedded in dry holes.

Overall, ultimate shear capacities ranged from 73.5 to 93.2 kips with an average of 82.2 kips. Excluding the results of two tests, the upper- and lower-bound values, ultimate shear capacities ranged from 77.0 to 85.6 kips with an average of 81.9 kips. Accordingly, ultimate shear capacities were all within 10 percent of the average, regardless of embedment length, installation condition, and testing age.

The significantly reduced tensile load capacity of anchors embedded in concrete with vinylester resin capsules under submerged conditions should be recognized in any design of anchor systems for underwater applications. For the types of anchors and installation conditions described herein, an ultimate tensile load of 24 kips is recommended for design of underwater anchor systems subjected to short duration loads. This load was determined by reducing the overall average tensile capacity at 0.1-in. displacement by the standard deviation. Appropriate factors of safety should be used to calculate the maximum allowable tensile load.

Keywords: cont'd on previous page

PREFACE

The tests described herein were authorized by the US Army Engineer District, New Orleans, by Intra-Army Order for Reimbursable Services No. LMNED-87-40, dated 24 March 1987. Funds for preparation and publication of this report were provided by Headquarters, US Army Corps of Engineers (HQUSACE), under Civil Works Research Work Unit 32303, "Application of New Technology to Maintenance and Minor Repair," for which Mr. James E. McDonald, Research Civil Engineer, Concrete Technology Division (CTD), Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES), is Principal Investigator. The work unit is part of the Concrete and Steel Structures Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program sponsored by HQUSACE. The Overview Committee at HQUSACE consists of Mr. James E. Crews (DAEN-CWO-M) and Dr. Tony C. Liu (DAEN-ECE-D). Technical Monitor for this study was Dr. Liu.

The study was performed at WES, SL, under the general supervision of Mr. Bryant Mather, Chief, and under the direct supervision of Mr. McDonald, who prepared this report. Mr. Kenneth L. Saucier was Acting Chief, CTD. Testing and data reduction activities were conducted by Mr. Roy L. Campbell, Sr., CTD. Ms. Carolyn Corbett, CTD, assisted in the data reduction. Final editing for publication of this report was provided by Mmes. Gilda Miller and Chris Habeeb, Editor and Editorial Assistant, respectively, Information Products Division, Information Technology Laboratory.

COL Dwayne G. Lee, EN, was Commander and Director of WES during publication of this report. Dr. Robert W. Whalin was Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
inches	25.4	millimetres
kips (force)	4.448222	kilonewtons
kips per square inch	6.894757	megapascals
miles (US statute)	1.609347	kilometres
pounds (force)	4,448.22	kilonewtons
pounds (force) per foot	14.5939	newtons per metre
pounds (force) per square inch	0.006894757	megapascals

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F-32)$. To obtain kelvin (K) readings, use: $K = (5/9)(F-32) + 273.15$.

EVALUATION OF VINYLESTER RESIN FOR ANCHOR EMBEDMENT IN CONCRETE

PART I: INTRODUCTION

Background

1. The Old River Low Sill Control Structure, located on the west bank of the Mississippi River about 40 miles* southwest of Natchez, Miss., was completed in 1960 to prevent the impending adoption of the Atchafalaya River's course as the lower Mississippi's main route to the Gulf of Mexico. The reinforced concrete structure has a gross length of 566 ft between abutments with 11 gate bays that have a 44-ft clear width between each pier. Flows through the structure are regulated by vertical lift, and steel gates are operated by traveling gantry cranes.

2. Abrasion-erosion damage in the stilling basin required repair in 1976 to protect the integrity of the overall structure. The most severe erosion was in the area between the end sill and the downstream row of baffles. Prefabricated modules of 1/2-in.-thick steel plate, anchored to the top of the end sill and to the floor slab directly behind the baffles, were used in the repair (McDonald 1980). Thirty modules, 24 ft long and from 3 to 22 ft wide, were installed. Prepackaged polyester resin grout was used to embed the steel anchors. The void between the steel plate and the existing concrete was filled with portland-cement grout. Repairs were accomplished underwater with careful use of partial gate closures to produce acceptable working conditions.

3. An underwater inspection of the repairs in 1977 revealed that 7 of the 30 modules had suffered at least partial loss of steel plate. A number of anchors were found broken either flush with the module plate, flush with the grout, or pulled completely out of the concrete (US Army Engineer District (USAED), New Orleans, 1977). A second diver inspection in 1978 revealed that additional steel plate had been ripped from the modules and that minor erosion was occurring in the stilling-basin slab upstream from some of the modules. Subsequent inspections revealed progressive damage to the modules

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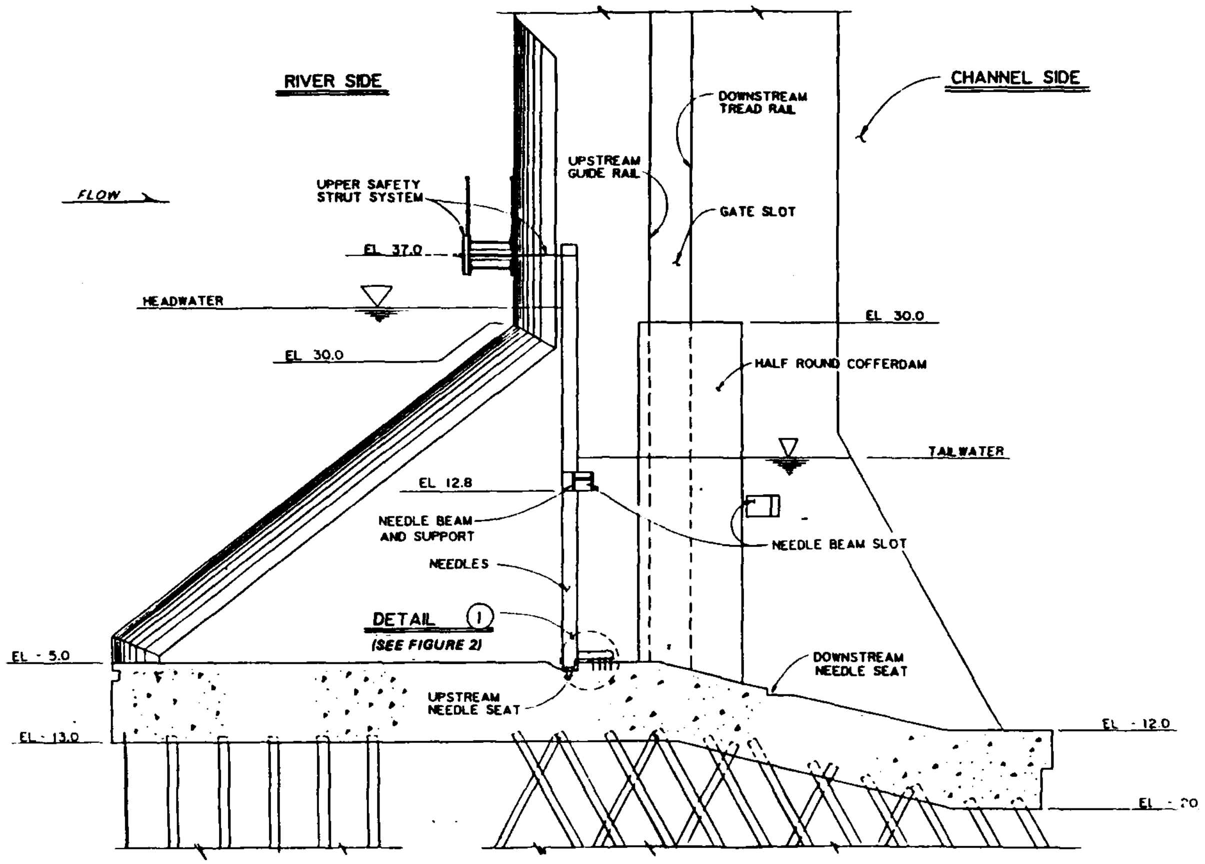
* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

until practically all of the steel plate had been lost. In addition, the 1986 diver inspection revealed damage to the gate guide rail system in the three low bays (New Orleans District 1986). Consequently, the features required to install the stop-log closure, both upstream and downstream of the gates, were inspected in the low bays. This inspection revealed damage to the needle seat recess (Figure 1).

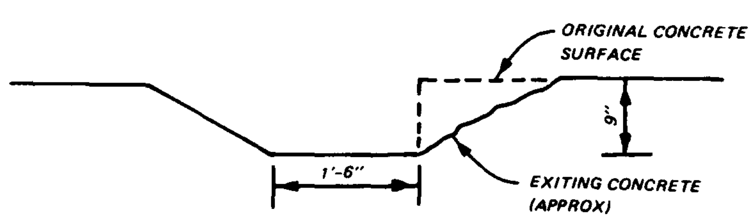
4. The planned dewatering of the stilling basin for inspection and repair in 1987 necessitated repair of the needle seat recess and the guide rail system. It was planned to restore the needle seat recess to its original configuration with steel plates (Figure 2). Once the 1-in.-thick steel plates were properly aligned, they would be anchored to the remaining concrete, and the void between the plates and the concrete would be filled with grout.

5. Since repair of the needle seat recess had to be done underwater, there was some concern as to the appropriate grout for embedding the anchors into the existing concrete. As a result of the reported failures of polyester resin grouted anchors in the stilling basin, the District was reluctant to specify polyester resin for additional underwater repairs. Laboratory tests showing that the pullout strength of anchors embedded in polyester resin under submerged conditions was significantly lower than the strength of comparable anchors installed under dry conditions (McDonald and Best 1986) intensified the District's reluctance to use polyester resin.

6. A review of available manufacturers' literature on concrete anchor grouting systems revealed that Hilti, Inc., was promoting an HEA vinylester resin adhesive as "the optimal solution for heavy duty fastenings in dry, wet and temperature-stressed base materials." According to the manufacturers' representatives, the performance of anchors embedded in vinylester resin under submerged conditions was similar to that of comparable anchors installed in the dry. However, no test data were furnished to substantiate this claim. Therefore, the US Army Engineer District, New Orleans requested that US Army Engineer Waterways Experiment Station initiate a study to evaluate the performance of anchors embedded in concrete with vinylester resin under a variety of test conditions.



a. Typical section



b. Condition of needle beam recess

Figure 1. Repair closure, Old River Low Sill Control Structure

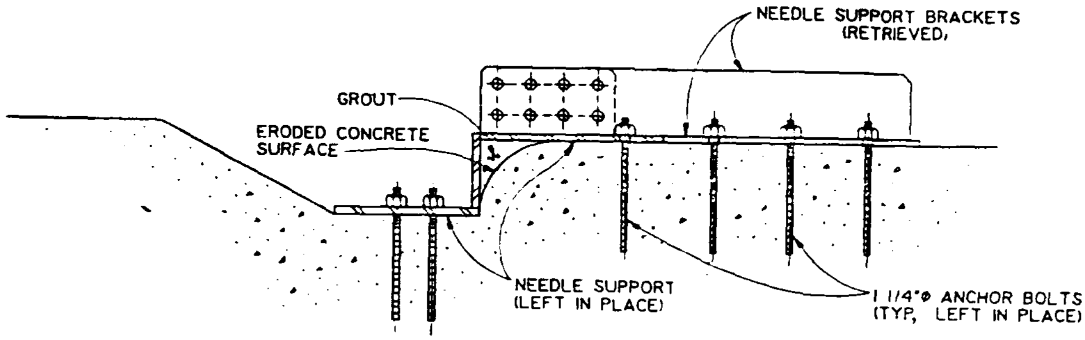


Figure 2. Needle seat recess repair

Purpose

7. The purpose of this study was to evaluate the load-carrying capacity of anchors embedded in concrete with vinylester resin grout.

Scope of Work

8. Originally, it was planned to install two types of anchors: No. 10 reinforcing steel bars and 1-1/4-in.-diam threaded steel rods. The number of anchors of each type was to be equally divided between dry and submerged installation in vertical drill holes 15 in. deep. Pullout tests were to be conducted at 1, 3, and 7 days age. Based on the 1-day test results, the study was expanded to include shear tests, and the number of tests at 3 days age was increased. Also, the effects of using a 12-in. embedment depth and various drill hole cleaning procedures were investigated. As a result of these changes in the study, the number of tests involving reinforcing bar anchors was greatly reduced to keep the study within the original time and funding constraints.

PART II: TESTING PROGRAM

Anchor Installation

9. Vertical holes were drilled in a mass concrete block to depths of 12 and 15 in. with a 1-1/2-in. outside-diameter core barrel. After the concrete cores were removed, half of the holes were filled with turbid water from the Mississippi River near Vicksburg, Miss. Drilling water in the remainder of the holes was removed with pressurized air. These holes were allowed to dry for a minimum of 3 days before anchors were installed.

10. Two types of anchors, high-strength threaded steel rods (American Society for Testing and Materials (ASTM) A-193 Grade B-7) and reinforcing steel bars (ASTM Grade 60) (ASTM 1983), were installed. Both types of anchors were 1-1/4 in. in diameter and 30 in. long. One end of each anchor had a flat chisel point, and the opposite end of the reinforcing bar was threaded for approximately 4 in.

11. Hilti's HEA capsules contain quartz sand, benzol peroxide hardening agent, and vinylester resin, all self-contained in a glass vial (Appendix A). Two sizes of capsules were used in these tests, 1 by 8-1/4 in. and 1-1/4 by 12 in. One capsule of each type was used in the 15-in. embedment holes. Under the direct supervision of Hilti personnel, the larger capsule was placed into the bottom of the drill holes, and the glass vial was crushed by repeated stabbing with the chisel point end of the anchor (Figure 3). A smaller capsule was then placed into the drill hole, and following a similar crushing of the vial, the anchor was immediately spun into the hole with an electric drill (Figure 4). The resin extruded from the dry holes was very cohesive, a fact which may account for the significant effort required to attain the full embedment depth.

12. A similar procedure was used to install the anchors under submerged conditions (Figure 5). However, the anchor installation required significantly less effort under submerged conditions. Approximately 45 sec was required to install an anchor under submerged conditions as compared with approximately 75 sec for anchor installation in a dry hole. Also, the extruded grout was much more fluid under wet conditions, and the creamy color contrasted with the black grout extruded under dry conditions. It appeared

Figure 3. Placing resin capsule in a dry hole

Figure 4. Anchor being spun into a dry hole

a. Capsule insertion

b. Anchor insertion

Figure 5. Anchor installation in hole containing water

that the turbid water was actually mixing with the vinylester resin during the anchor installation process.

13. Similar procedures were used for the 12-in. embedment holes; however, only one capsule (1-1/4 by 12 in.) was used in each installation. Also, the anchors were shortened to 27-in. lengths.

Testing Equipment and Procedures

14. A hollow core hydraulic ram and an electrically powered hydraulic pump were used to load the anchors in both the tensile and shear tests. A universal laboratory testing machine was used to calibrate the loading system with results as shown in Figure 6.

15. In the pullout tests, the hydraulic ram was positioned over the anchor to be tested and secured with a nut threaded onto the end of the anchor (Figure 7). A mechanical dial gage was positioned on the end of the anchor to measure displacement of the anchor relative to the concrete surface. The loading rate in the pullout tests was approximately 3,350 lb-ft/min with 3-min intervals at each increment of load. Generally, three-load increments of 2,000-psi gage pressure each were initially applied to anchors installed in dry holes. Smaller increments were applied beyond 6,000 psi depending on the magnitude of anchor displacement. Two initial-load increments of 1,000 psi each were applied to anchors installed under submerged conditions with smaller increments applied beyond 2,000 psi.

16. Horizontal shear loads were applied to the anchors through a donut-shaped steel collar positioned around the anchor (Figure 8). A high-strength steel rod was used to transfer load from the hydraulic ram through the collar to the anchor. Grouted anchors were used to mount a reaction beam on the sides of the concrete block. A linear variable differential transformer (LVDT) gage was positioned against the collar opposite the load transfer rod to monitor horizontal movement of the anchor near the surface of the concrete block. Shear loads were applied continuously at a rate of approximately 6,700 lb-ft/min, up to failure of the anchor.

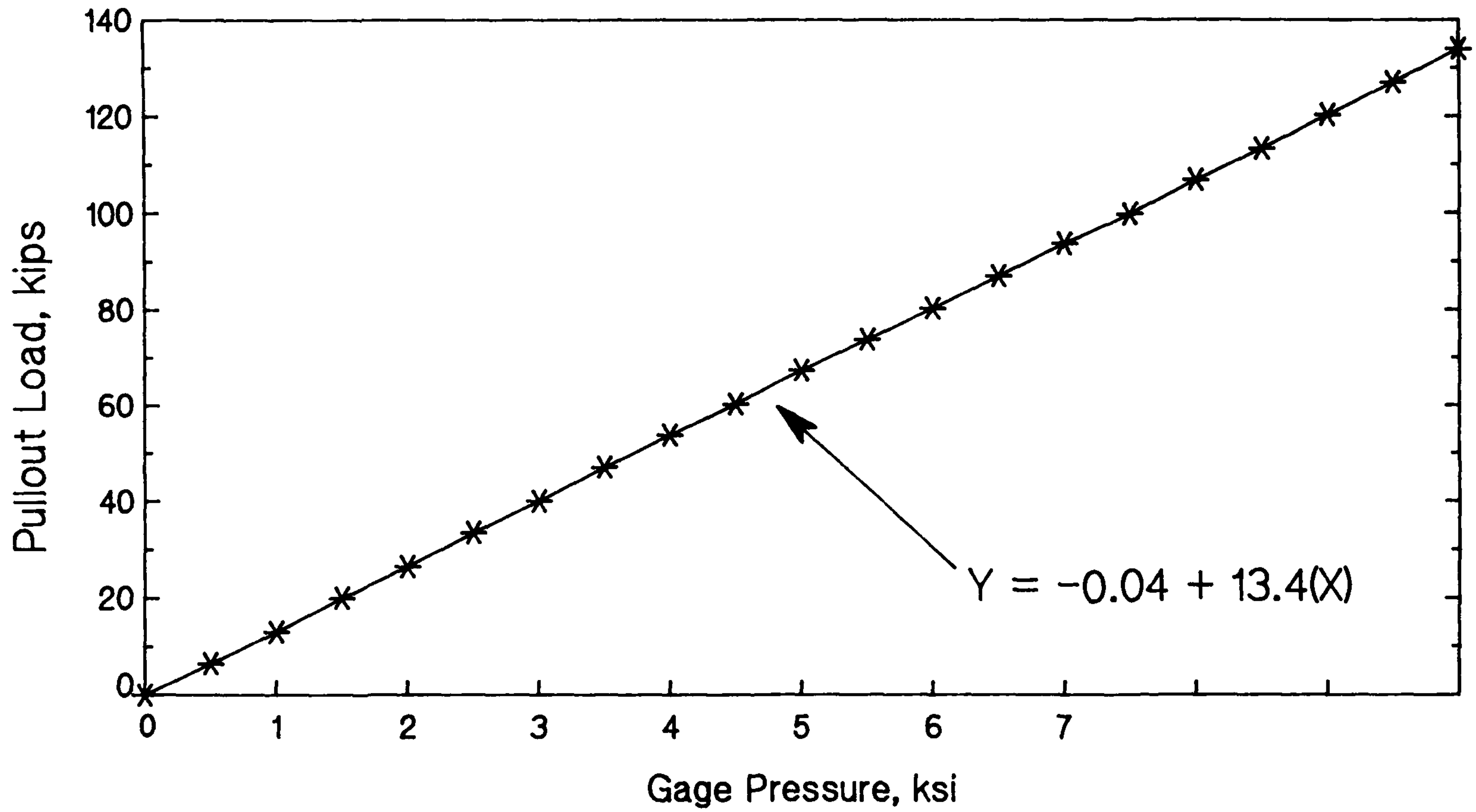
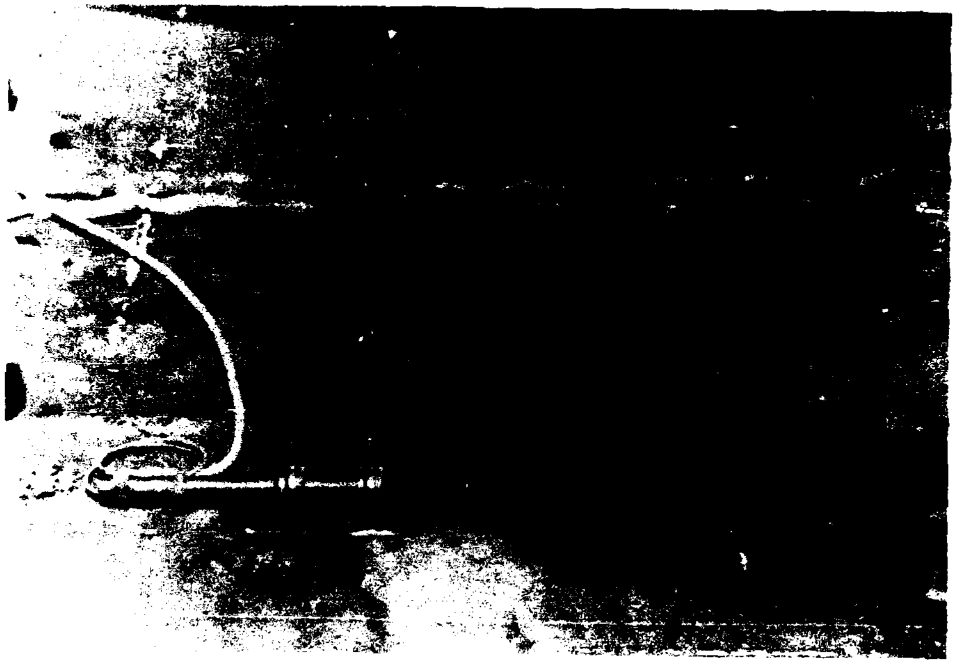


Figure 6. Calibration curve for hydraulic loading system

a. Closeup view

b. Overall view

Figure 7. Pullcut tests in progress



a. Closeup view of collar and LVDT gage

b. Overall view

Figure 8. Arrangement of shear test equipment

PART III: TEST RESULTS AND DISCUSSION

Pullout Tests

17. Results of pullout tests conducted at 1 day age on anchors with 15-in. embedment lengths are shown in Figure 9. Anchors embedded in dry holes exhibited small displacements at loads to approximately 105 kips. However, beyond this load the anchors exhibited significant displacement with relatively small increases in applied tensile load. In comparison, anchors embedded under submerged conditions did not exhibit bilinear load-displacement curves, making it difficult to determine precisely the load at which bond failure occurred at the grout-concrete interface. Therefore, pullout loads at displacements of 0.1 and 0.2 in., in addition to the ultimate load, were selected as a basis for comparison of anchor performance under the various installation conditions. On this basis, results of the 1-day tests are summarized as follows:

Anchor No.	Installation Condition		Load, kips 0.1-in. Displ	0.2-in. Displ	Ultimate
2	Dry		106.1	119.0	131.0
11	Dry		104.5	117.2	124.3
		Avg	105.3	118.1	127.7
24	Submerged		41.5	45.6	55.6
26	Submerged		19.6	26.1	30.9
29	Submerged		20.3	25.9	34.7
		Avg	27.1	32.5	40.4

18. The tensile load capacity of anchors embedded in vinylester resin was significantly reduced when the anchors were installed in holes containing turbid water. At a displacement of 0.1 in., the average tensile capacity of anchors embedded under submerged conditions was 27.1 kips, approximately one-fourth that of similar anchors installed under dry conditions.

19. An inspection of the anchors after they were tested revealed that failure occurred through loss of bond at the grout-concrete interface. This bond loss was especially evident for anchors installed under submerged conditions as shown in Figure 10. In an effort to determine the cause of the relatively poor performance of the anchors installed under submerged conditions,

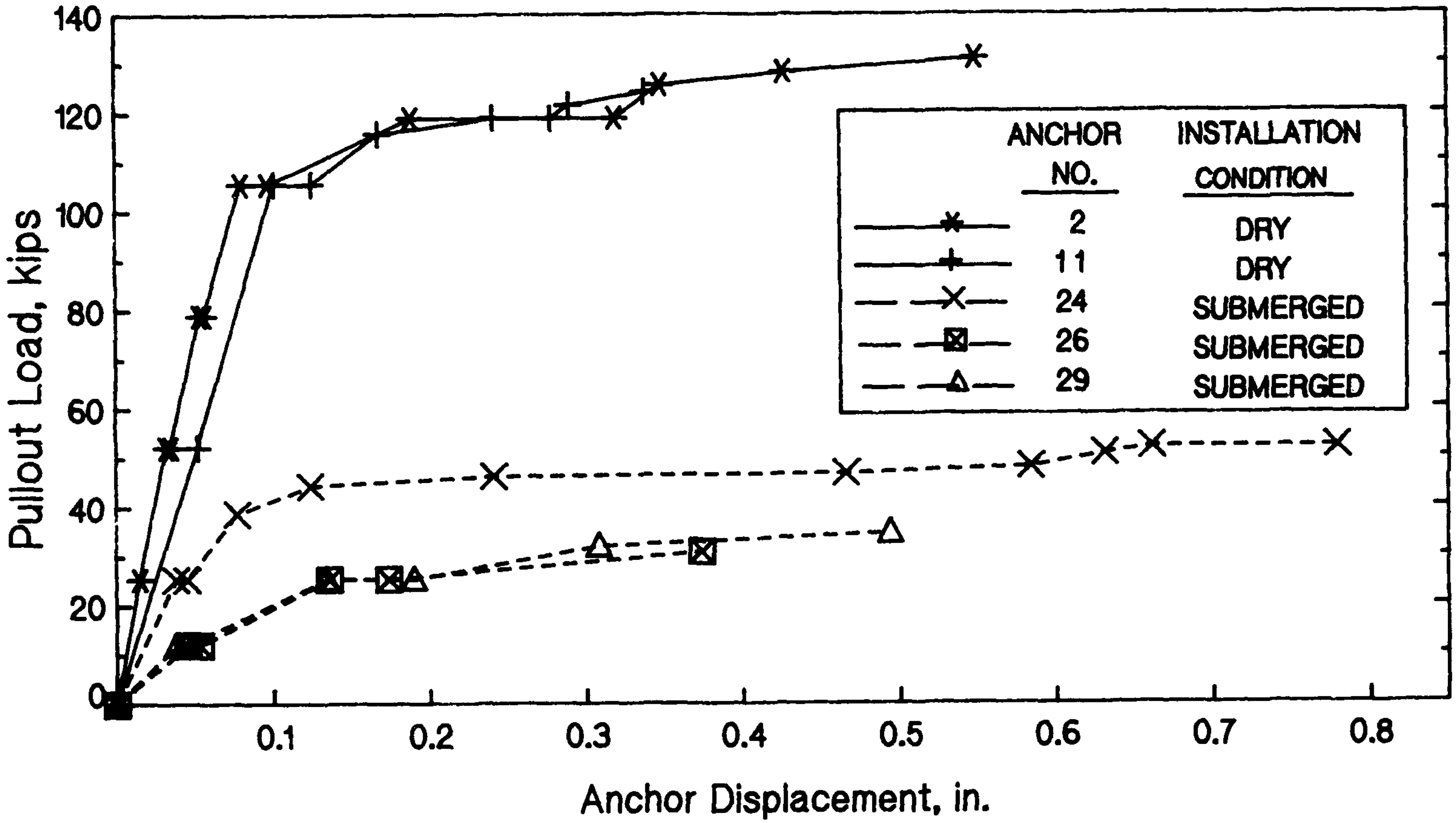


Figure 9. Results of pullout tests conducted at 1-day age on anchors with 15-in. embedment lengths

Figure 10. Typical failure of anchors installed in holes containing turbid water

anchors were pulled completely out of the drill holes to allow inspection of the vinylester grout (Figure 11). The grout was very soft and was easily removed from the anchors by hand. After being cleaned with a wire brush, the anchors were reinstalled for additional testing.

20. Results of pullout tests conducted at 3 days age on anchors with 15-in. embedment lengths are shown in Figure 12 and summarized in the following:

Anchor No.	Installation Condition	Load, kips 0.1-in. Displ	0.2-in. Displ	Ultimate
14	Dry	100.0	112.0	123.9
15	Dry	104.7	114.9	124.3
		Avg 102.4	113.4	124.1
18	Submerged	25.4	30.2	48.1
19	Submerged	37.3	42.0	56.1
22	Submerged	29.9	38.7	38.7
23	Submerged	50.9	58.6	58.8
		Avg 35.9	42.4	50.4

Figure 11. Typical grout condition for anchors installed in holes containing turbid water

Uniform results were obtained in tests on the two anchors installed in dry holes. These results were similar to those obtained in 1-day tests on anchors installed under dry conditions. In comparison, tests on the four anchors installed under submerged conditions yielded relatively erratic results with pullout loads ranging from 25.4 to 50.9 kips at 0.1-in. displacement. At this displacement, the average tensile capacity of anchors installed in holes containing turbid water was 35.9 kips, approximately 35 percent of the capacity exhibited by similar anchors installed under dry conditions.

21. Results of pullout tests conducted at 7 days age on anchors with 15-in. embedment lengths are shown in Figure 13 and summarized in the following:

Anchor No.	Installation Condition		Load, kips 0.1-in. Displ	0.2-in. Displ	Ultimate
7	Dry		111.7	121.0	127.8
10	Dry		105.6	115.5	122.6
		Avg	108.7	118.3	125.2
27	Submerged		59.4	72.8	76.6
30	Submerged		52.1	60.1	60.1
		Avg	55.7	66.5	68.4

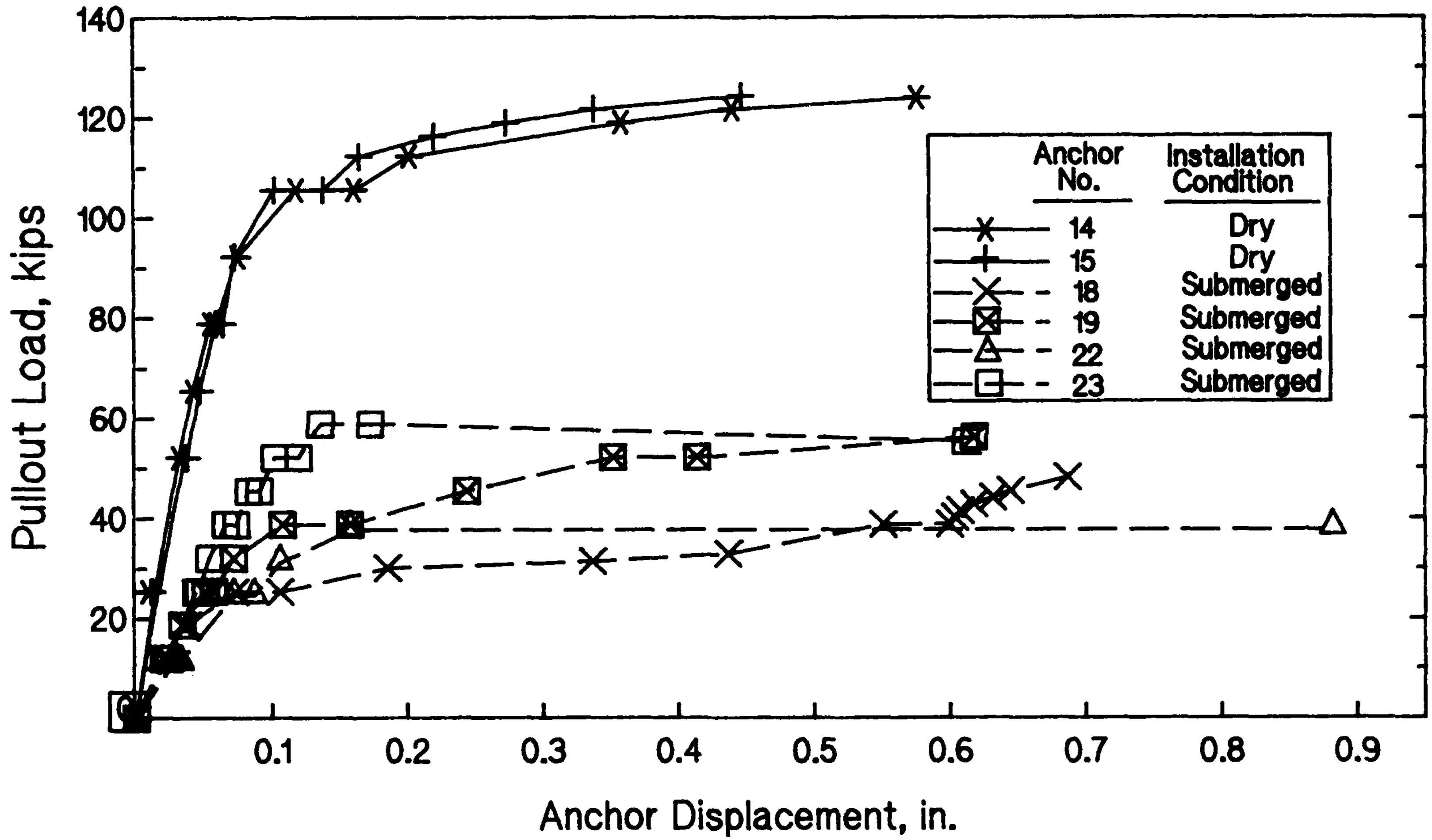


Figure 12. Results of pullout tests conducted at 3 days age on anchors with 15-in. embedment lengths

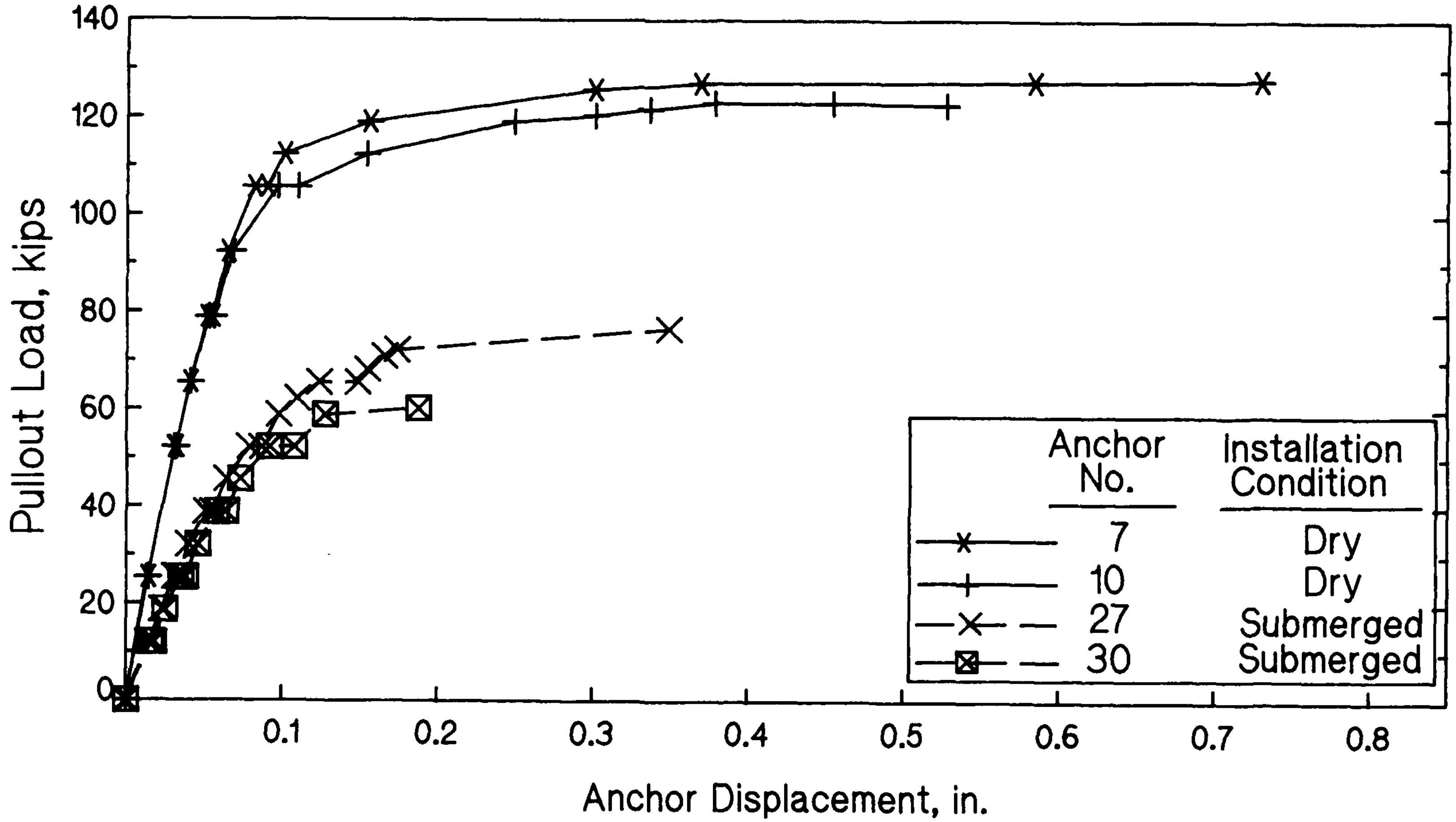


Figure 13. Results of pullout tests conducted at 7 days age on anchors with 15-in. embedment lengths

Results of tests on anchors installed in dry holes were similar to results of previous tests on similar anchors at 1 and 3 days age. Tests on the two anchors installed under submerged conditions yielded more uniform results than those obtained in similar tests at earlier ages. At a displacement of 0.1 in., the average tensile capacity of anchors embedded in holes containing turbid water was approximately one-half that of similar anchors installed in dry holes.

22. A limited number of anchors with 15-in. embedment lengths were available for pullout testing at 28 days age. Results of these tests are shown in Fig''re 14 and summarized in the following:

Anchor No.	Installation Condition	Load, kips 0.1-in. Displ	0.2-in. Displ	Ultimate
1	Dry	99.1	ı05.6	105.6
6	Dry	105.6	114.2	131.0*
		Avg 102.4	109.9	118.3
17	Submerged	25.4	26.8	30.7

* Test discontinued at maximum load capacity of testing system.

Results of tests on the two anchors installed in dry holes were similar to results of previous tests on similar anchors at earlier ages. In fact, at 0.1-in. displacement the average tensile capacity was identical to that at 3 days age. In earlier tests on anchors embedded in holes containing turbid water, results indicated an increase in tensile capa:ity with increasing age (Figure 15). However, results of the one test conducted at 28 days age did not fo]low this trend. Results of the 28-day test were essentially the same as previously obtained in tests on two (Nos. 26 and 29) of the three similar anchors tested at 1 day age.

23. Four drill holes (15-in. depth) were cleaned by being flushed with tap water until the return water was clear. Following the flushing, two of the holes were cleaned with pressurized air and allowed to air-dry for a minimum of 3 days prior to anchor installation. The remaining holes were kept full of tap water. Anchors were installed as previously described for both the dry and the submerged conditions. Results of pullout tests on those anchors installed in dry holes that had been flushed are compared with results of

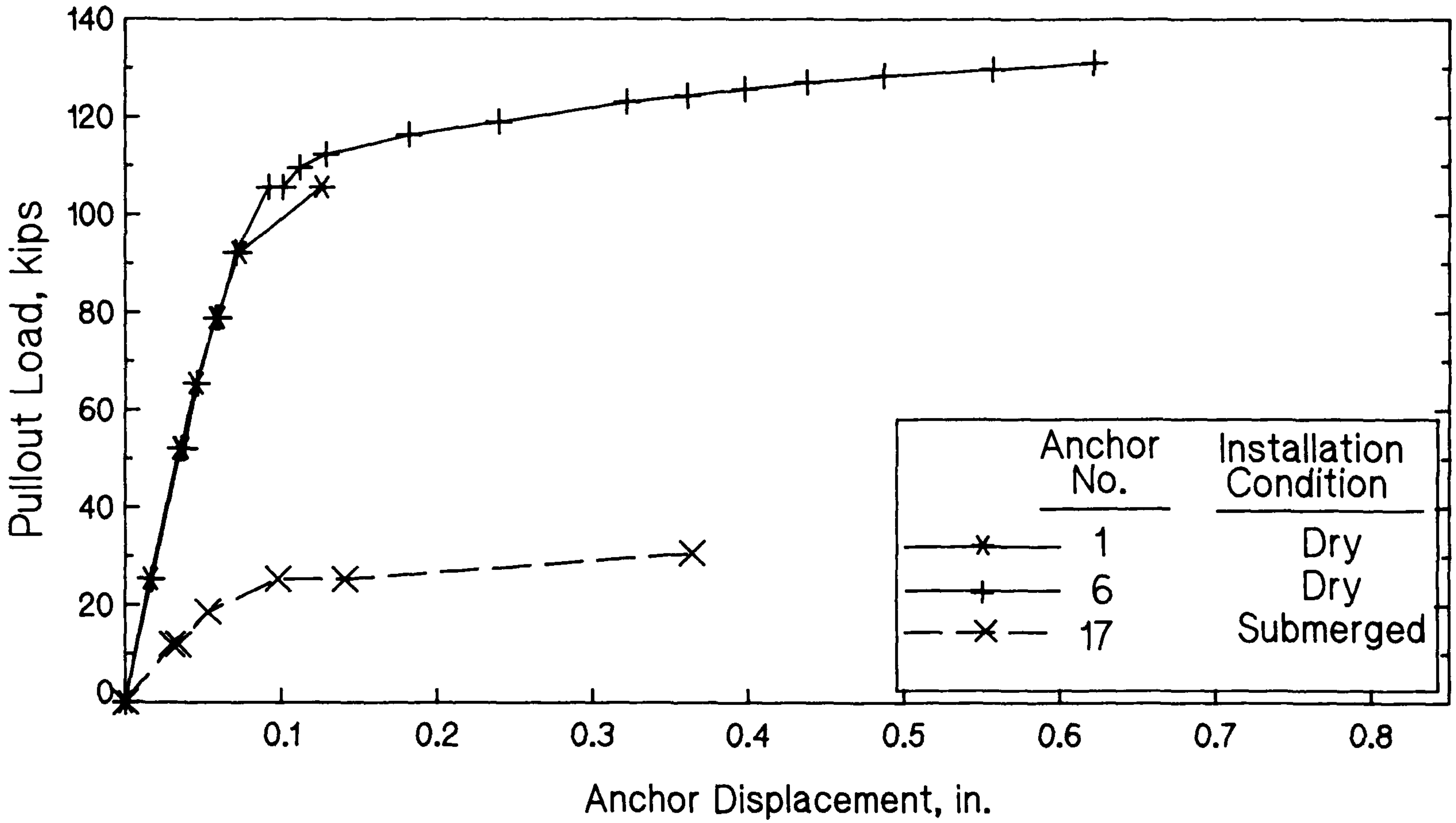


Figure 14. Results of pullout tests conducted at 28 days age on anchors with 15-in. embedment lengths

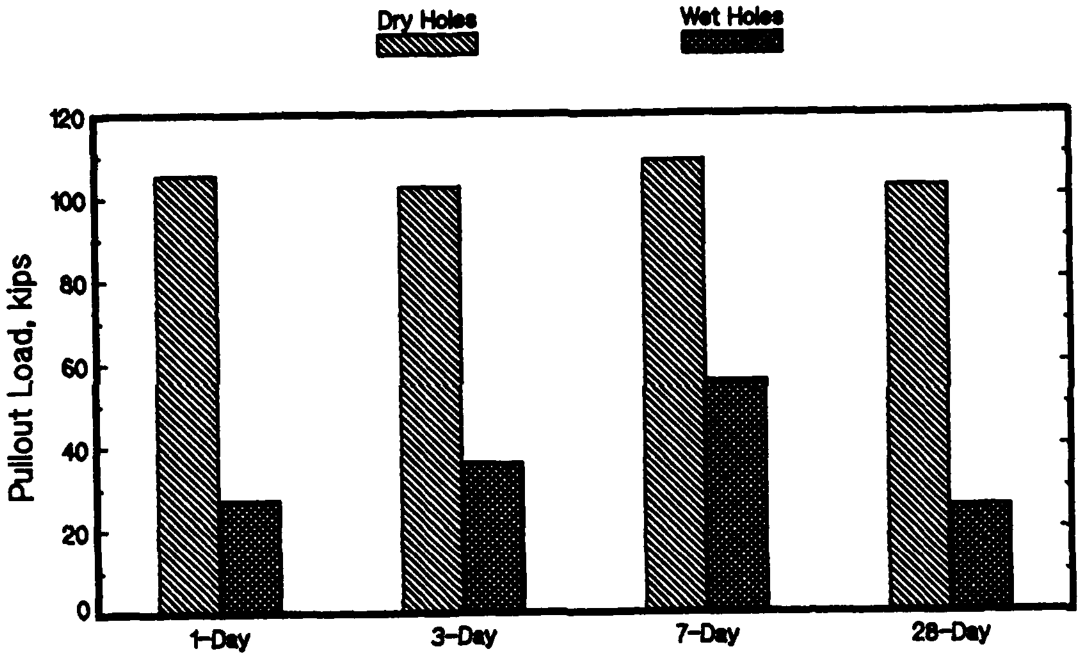


Figure 15. Summary of pullout test results at 0.1-in. displacement for anchors with 15-in. embedment lengths

previous tests on anchors installed in as-drilled holes in Figure 16 and in the following:

Anchor No.	Hole Condition	Load, kips 0.1-in. Displ	0.2-in. Displ	Ultimate
14	As-drilled	100.0	112.0	123.9
15	As-drilled	104.7	114.9	124.3
		Avg 102.4	113.4	124.1
3	Flushed	106.8	118.1	124.3*
4	Flushed	109.9	119.1	125.7*
		Avg 108.3	118.6	125.0

* Test discontinued at maximum load capacity of the testing system.

At displacements of 0.1 and 0.2 in., the average tensile capacity of anchors installed in the flushed holes was approximately 5 percent higher than that of similar anchors installed in as-drilled holes. The ultimate tensile capacity of anchors installed in the flushed holes exceeded the loading capacity of the testing system. However, results of the displacement measurements at maximum load (Figure 16) and cracks observed at the grout-concrete interface indicated

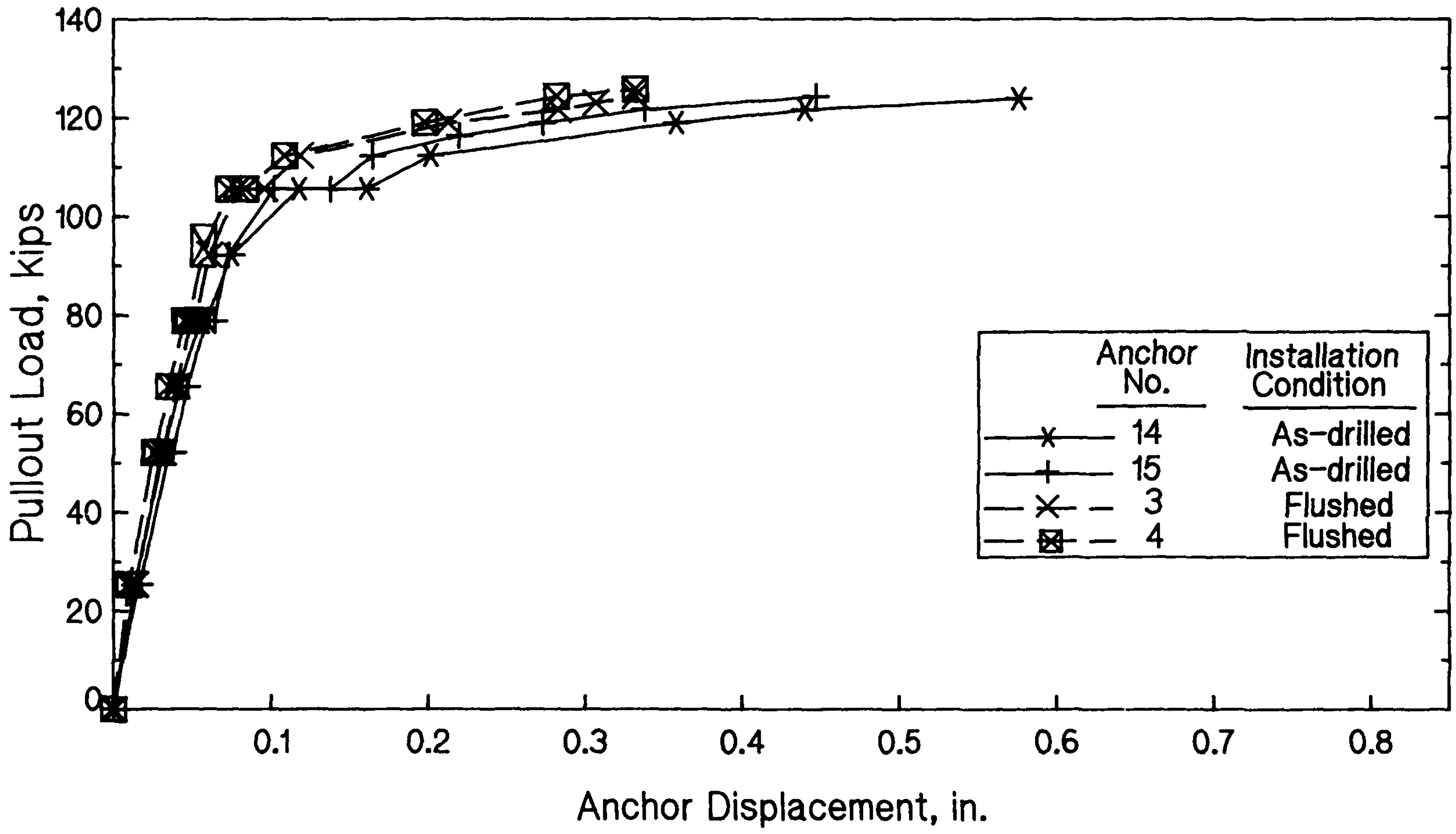


Figure 16. Results of pullout tests conducted at 3 days age on anchors installed in dry holes with 15-in. embedment lengths

the ultimate load would follow the trend established at 0.1- and 0.2-in. displacements.

24. Results of pullout tests conducted at 3 days age on anchors installed under submerged conditions in flushed holes are compared with results of previous tests on anchors installed in as-drilled holes in Figure 17. These tests are summarized in the following:

Anchor No.	Hole Condition		Load, kips 0.1-in. Displ	0.2-in. Displ	Ultimate
18	As-drilled		25.4	30.2	48.1
19	As-drilled		37.3	42.0	56.1
22	As-drilled		29.9	38.7	38.7
23	As-drilled		50.9	58.6	58.8
		Avg	35.9	42.4	50.4
31	Flushed		44.4	52.1	61.2
32	Flushed		33.1	38.0	39.8
		Avg	38.7	45.1	50.5

Cleaning the drill holes by flushing with tap water resulted in only marginal improvement in the performance of anchors installed under submerged conditions. At displacements of 0.1 and 0.2 in., the tensile capacity of anchors installed in holes flushed with tap water averaged only 7 percent higher than that of anchors installed in as-drilled holes containing turbid water. The average ultimate tensile capacity was essentially the same for both conditions.

25. Two other holes in the wet environment were reamed with a cruciform bit and cleaned with a bristle brush during the flushing process. Results of pullout tests on anchors installed under submerged conditions in these cleaned holes are compared with results of previous tests on anchors installed in as-drilled holes in Figure 18. These tests, conducted at 3 days age, are summarized in the following:

Anchor No.	Hole Condition		Load, kips 0.1-in. Displ	0.2-in. Displ	Ultimate
24a	Cleaned		32.1	38.7	38.7
34	Cleaned		35.3	46.4	47.0
		Avg	33.7	42.6	42.9

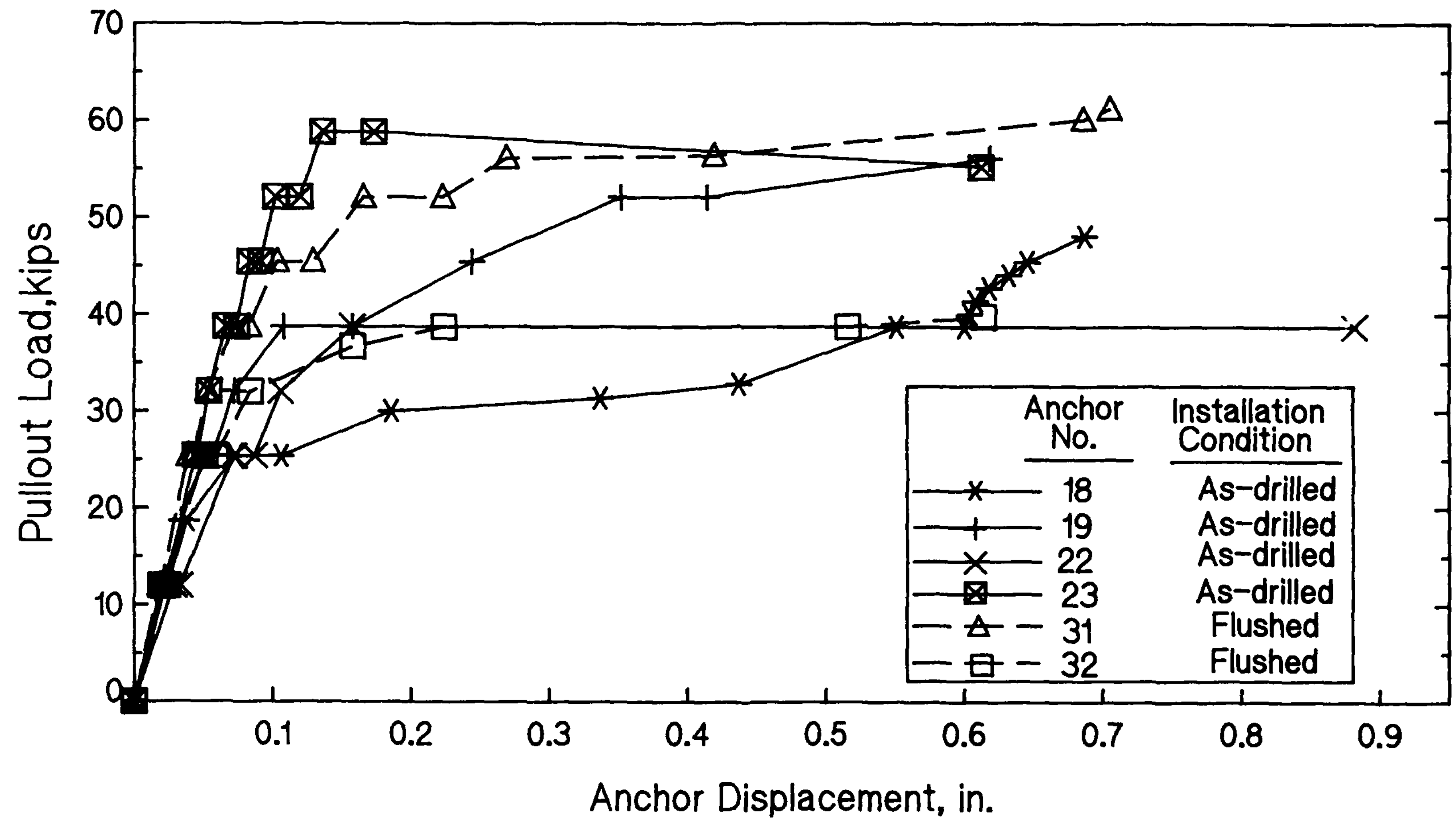


Figure 17. Results of pullout tests conducted at 3 days age on anchors with 15-in. embedment lengths installed in as-drilled and flushed holes under submerged conditions

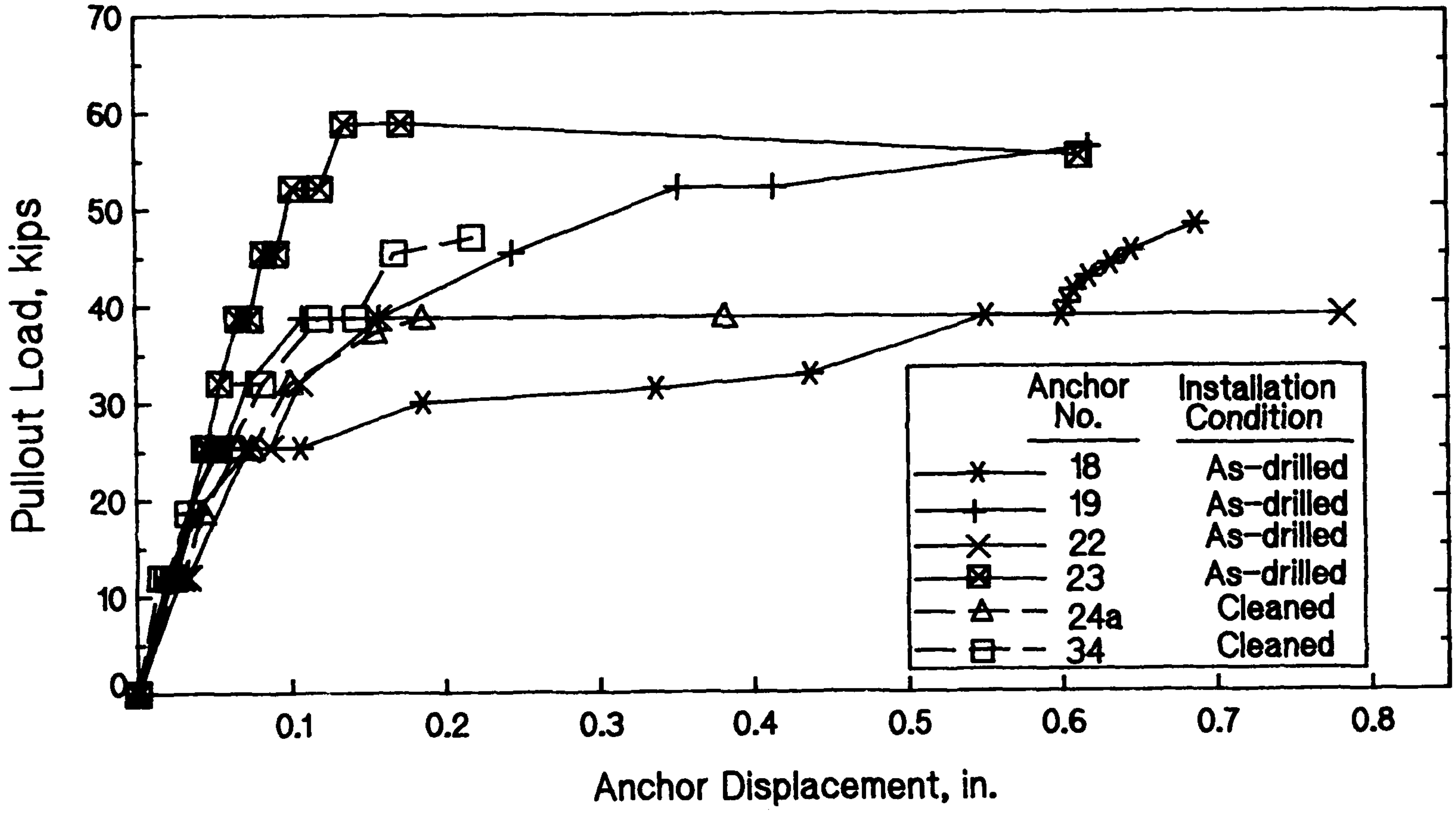


Figure 18. Results of pullout tests conducted at 3 days age on anchors with 15-in. embedment lengths installed in as-drilled and cleaned holes under submerged conditions

In the limited number of tests conducted, attempts to optimize cleanliness of the drill hole prior to submerged anchor installation failed to increase the average tensile capacity. In comparison to the flushed conditions, this additional cleaning actually resulted in a slight decrease in the average tensile capacity of anchors installed under submerged conditions (Figure 19).

26. To evaluate the effect of reduced embedment lengths, anchors with 12-in. embedments were installed under both dry and submerged conditions. Results of pullout tests conducted at 3 days age on these anchors are shown in Figure 20 and summarized in the following:

Anchor	Installation	Load, kips		
No.	Condition	0.1-in. Displ	0.2-in. Displ	Ultimate
38	Dry (flushed)	108.1	116.1	119.8
39	Dry (flushed)	101.6	111.7	119.4
41	Dry (flushed)	105.6	113.9	125.4
		Avg 105.1	113.9	121.5
44	Submerged (as-drilled)	24.8	27.2	32.5
46	Submerged (as-drilled)	33.6	38.7	43.7
48	Submerged (as-drilled)	45.1	52.1	54.5
		Avg 34.5	39.3	43.6

At displacements of 0.1 and 0.2 in., the average tensile capacity of anchors with 15-in. embedment lengths installed in dry holes which had previously been flushed was 3 and 4 percent higher, respectively, than that of anchors with 12-in. embedments similarly installed (Figure 21). The ultimate tensile capacity of anchors with 15-in. embedment exceeded the loading capacity of the testing system. However, the maximum applied loads averaged 3 percent higher than the ultimate tensile capacity of anchors with 12-in. embedment. Anchors with 12-in. embedment lengths installed in as-drilled holes under submerged conditions also exhibited small reductions in average tensile capacity compared to similar anchors with 15-in. embedments. These reductions ranged from 4 percent at 0.1-in. displacement to 14 percent at ultimate load (Figure 22).

27. The effects of installation condition on the performance of anchors with 12-in. embedment lengths were similar to those previously reported for 15-in. embedments. Under dry conditions, the relatively uniform test results exhibited bilinear load-displacement curves with an average tensile capacity at 0.1-in. displacement in excess of 100 kips. In comparison, the more erratic results of tests on anchors installed in holes containing turbid water

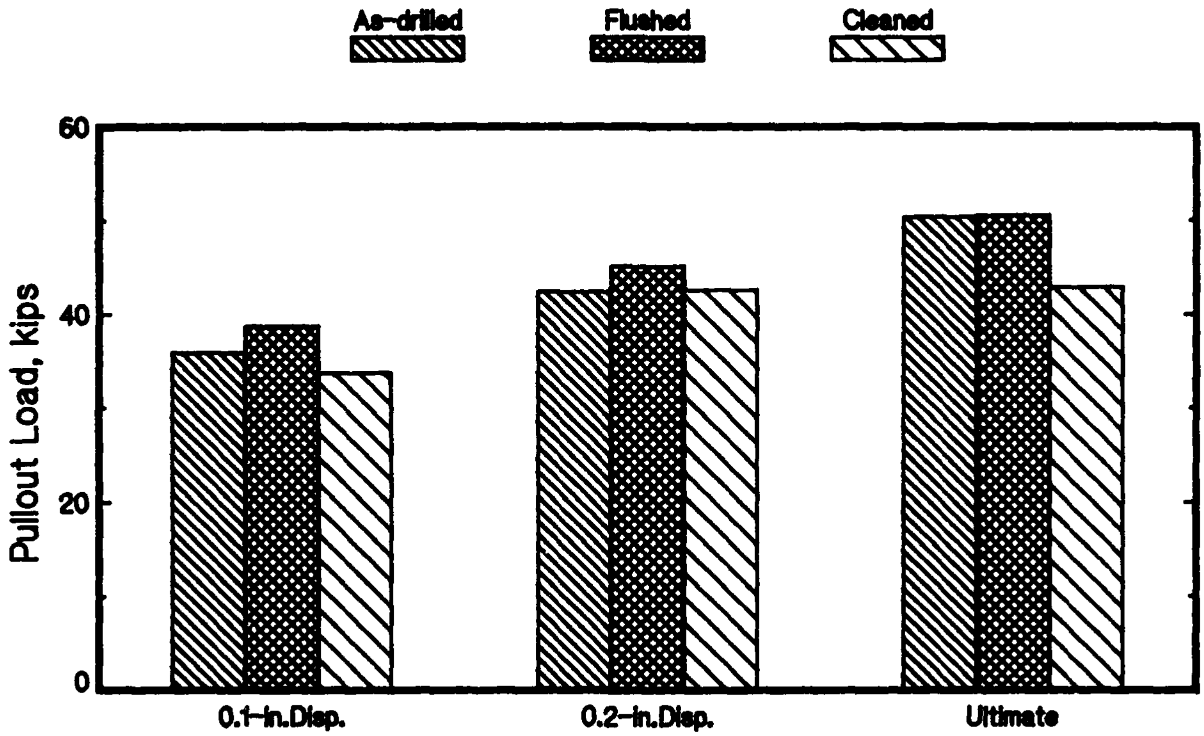


Figure 19. Summary of pullout test results for anchors installed in holes of varying cleanliness under submerged conditions

did not exhibit a clearly defined point of bond failure. At 0.1-in. displacement, the tensile capacity ranged from 24.8 to 45.1 kips with an average of 34.5 kips, approximately one-third that of similar anchors installed under dry conditions (Figure 23).

28. A limited number of tests were conducted to evaluate the performance of No. 10 reinforcing bars as anchors. Of the three reinforcing-bar anchors installed under submerged conditions in holes that had been previously flushed, only one (No. 37) had the full 15-in. embedment length. The remaining anchors, Nos. 35 and 36, could not be installed beyond depths of 12-3/8 and 13-1/4 in., respectively. This difficulty in installation was attributed primarily to the nominal 1-1/2-in.-diam drill hole recommended by Hilti, Inc. This small hole size combined with bar deformations oriented perpendicular to the longitudinal axis of the bars (Nos. 35 and 36) prevented extrusion of the excess grout. In comparison, bar deformations on anchor No. 37 were inclined with respect to the longitudinal axis. This orientation apparently aided in grout extrusion, and it was possible to achieve full depth embedment, albeit with some difficulty.

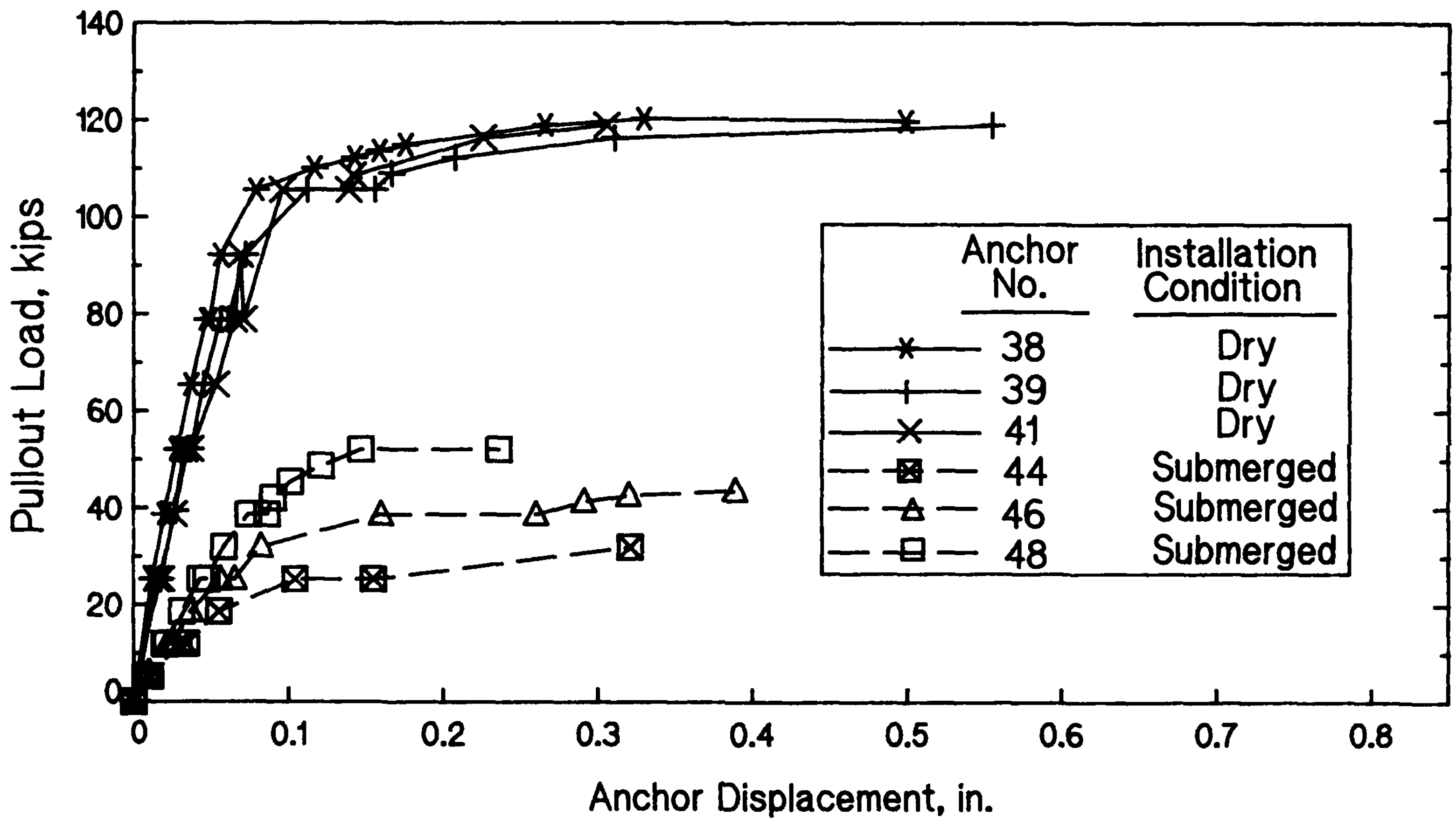


Figure 20. Results of pullout tests conducted at 3 days age on anchors with 12-in. embedment lengths

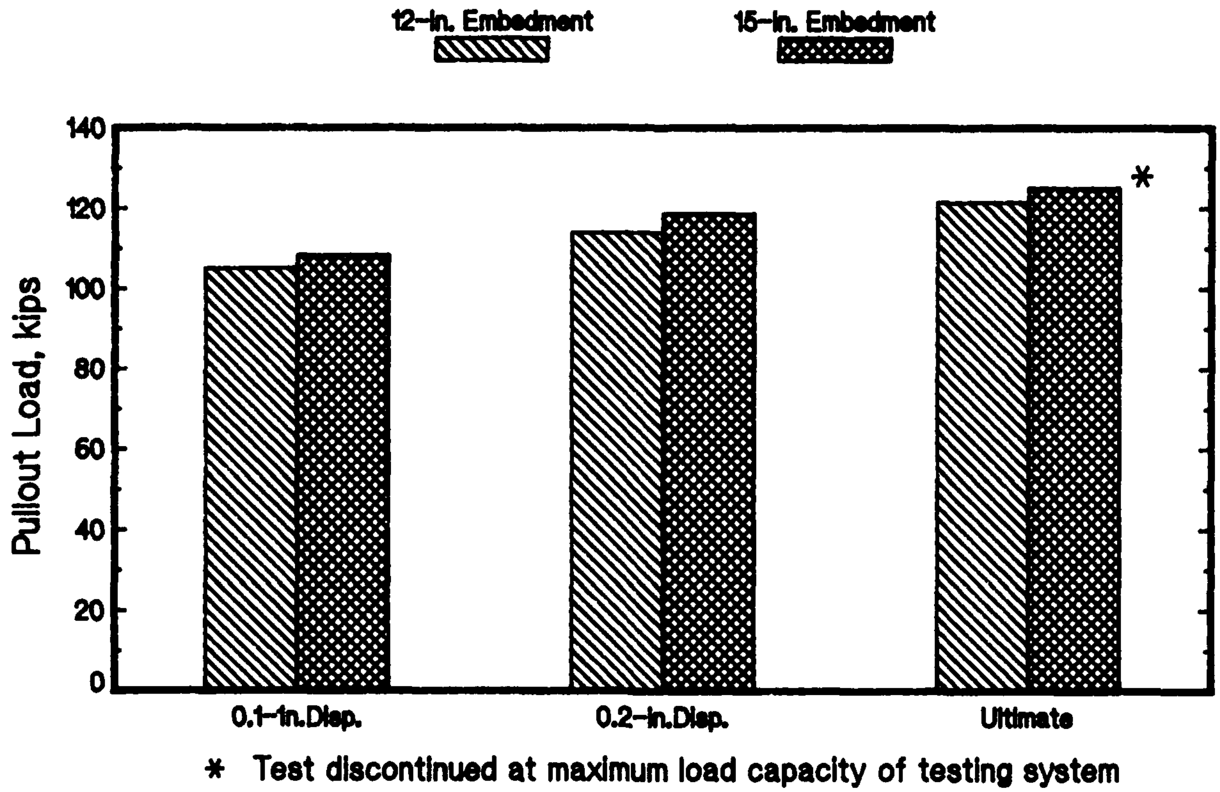


Figure 21. Effect of embedment length on tensile capacity of anchors installed in dry holes

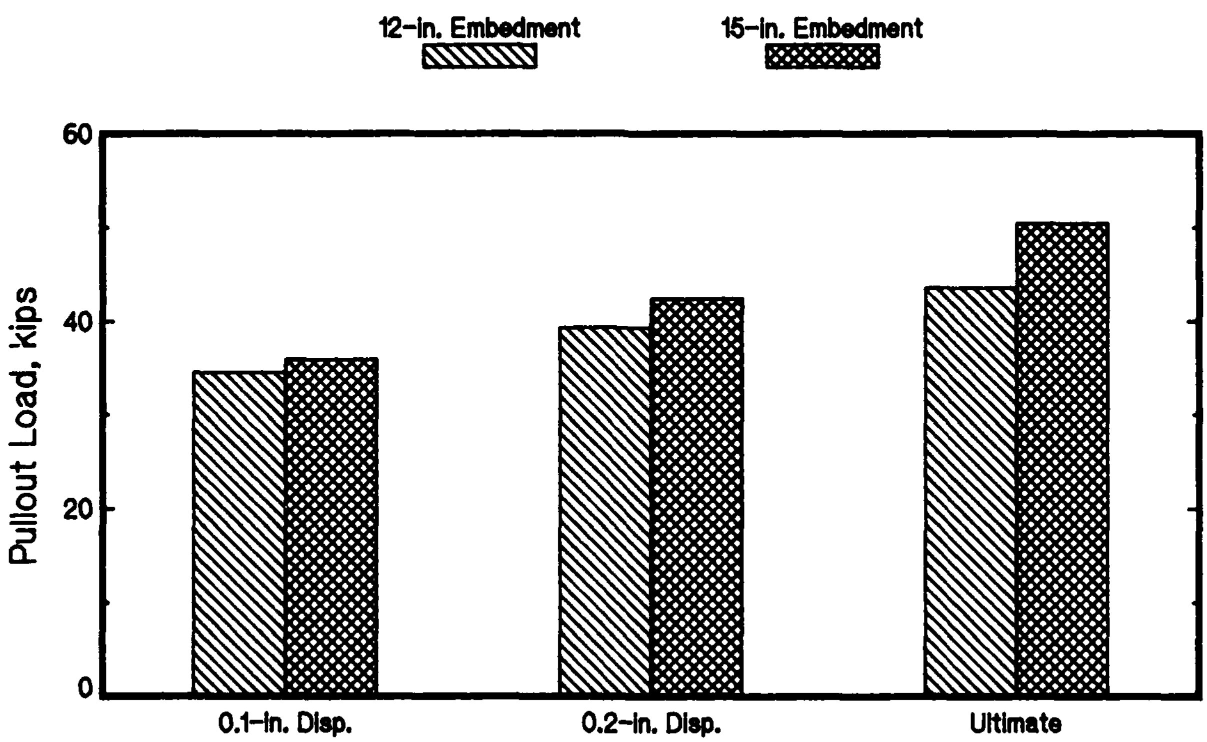


Figure 22. Effect of embedment length on tensile capacity of anchors installed under submerged conditions

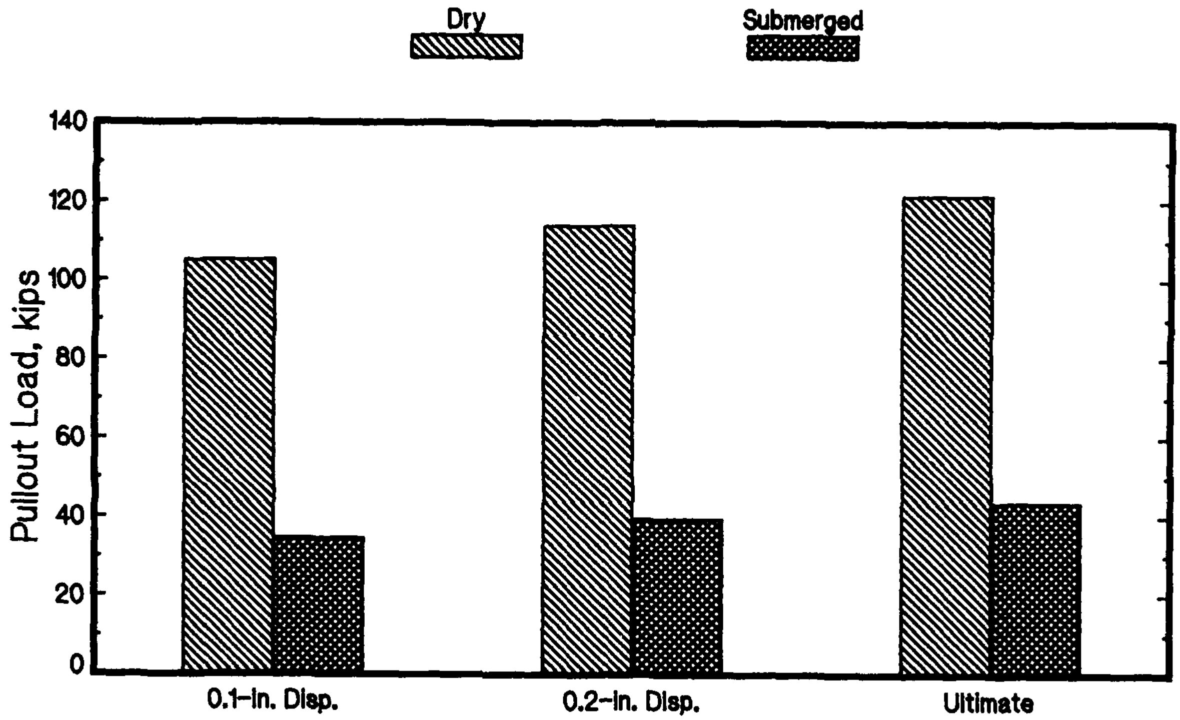


Figure 23. Summary of pullout test results for anchors with 12-in. embedment lengths

29. Results of pullout tests on reinforcing-bar anchors are compared with results of previous tests on threaded-rod anchors installed under similar conditions in Figure 24. Results of these tests, conducted at 3 days age, are summarized in the following:

Anchor No.	Hole Condition	Load, kips 0.1-in. Displ	0.2-in. Displ	Ultimate
35	Flushed	20.3	25.4	38.7
36	Flushed	36.7	48.6	56.1
37	Flushed	25.4	38.7	49.4
	Avg	27.5	37.6	48.1

With the exception of anchor No. 35, which had only 12-3/8-in. embedment, the performance of reinforcing-bar anchors was similar to that of the threaded-rod anchors. Excluding anchor No. 35 from the comparison of anchor types (Figure 25), the average tensile capacity of the reinforcing-bar anchors at 0.1-in. displacement was approximately 20 percent less than that of the threaded-rod anchors. However, at 0.2-in. displacement and at ultimate load, average

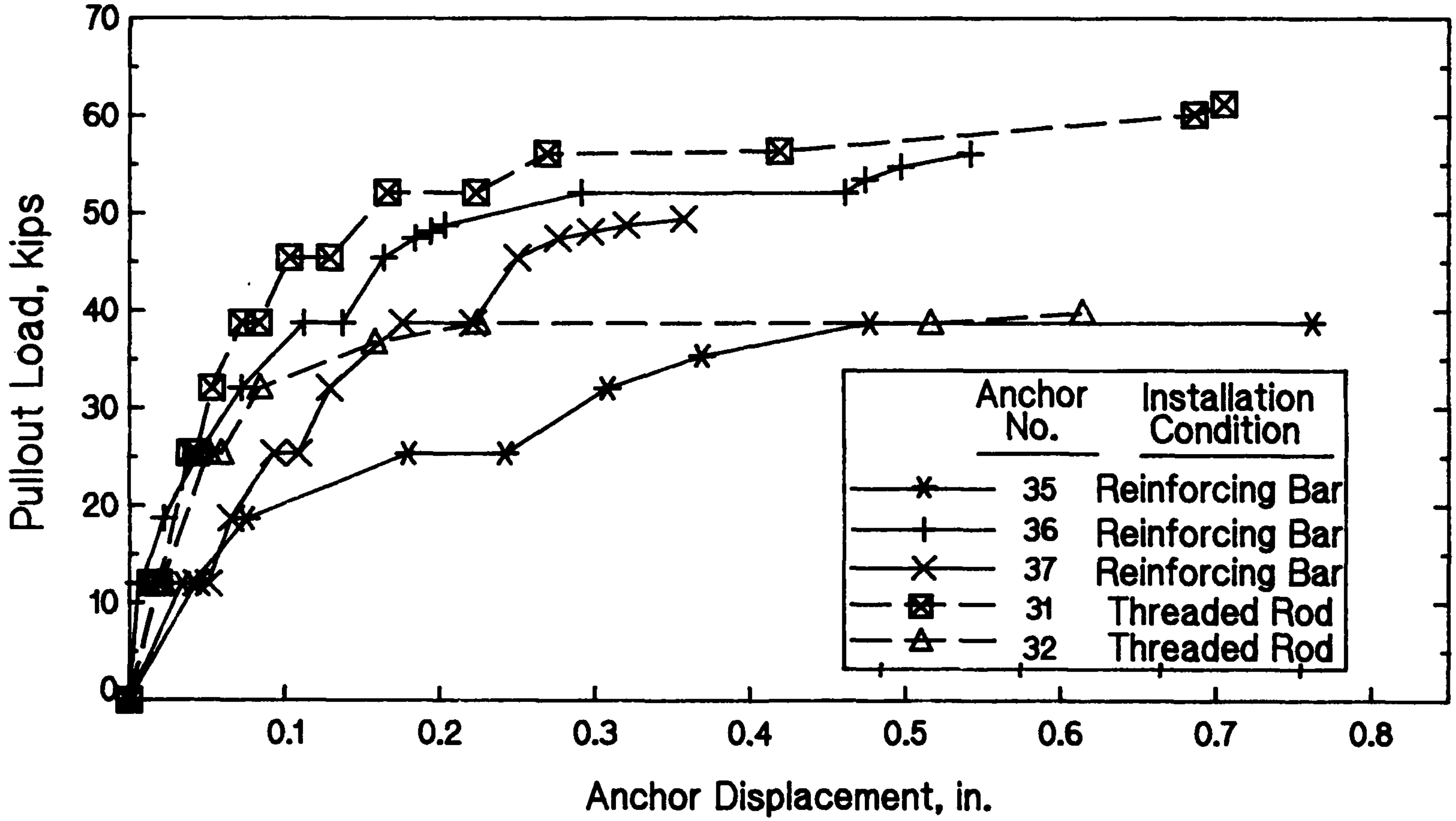


Figure 24. Results of pullout tests conducted at 3 days age on two types of anchors

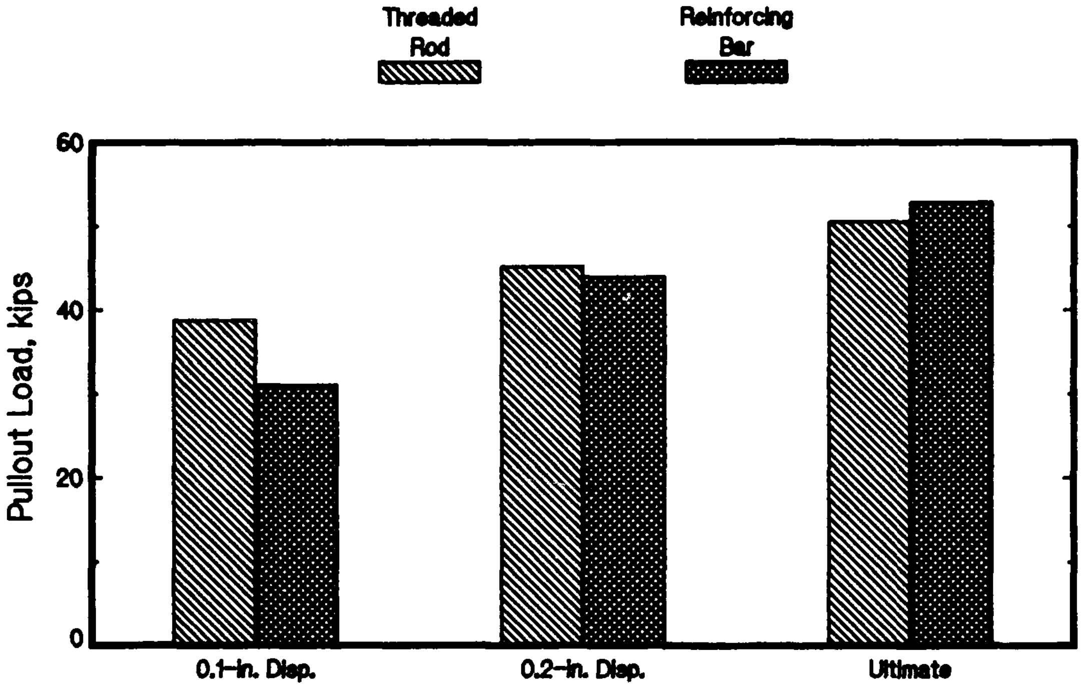


Figure 25. Comparison of threaded-rod and reinforcing bar anchors

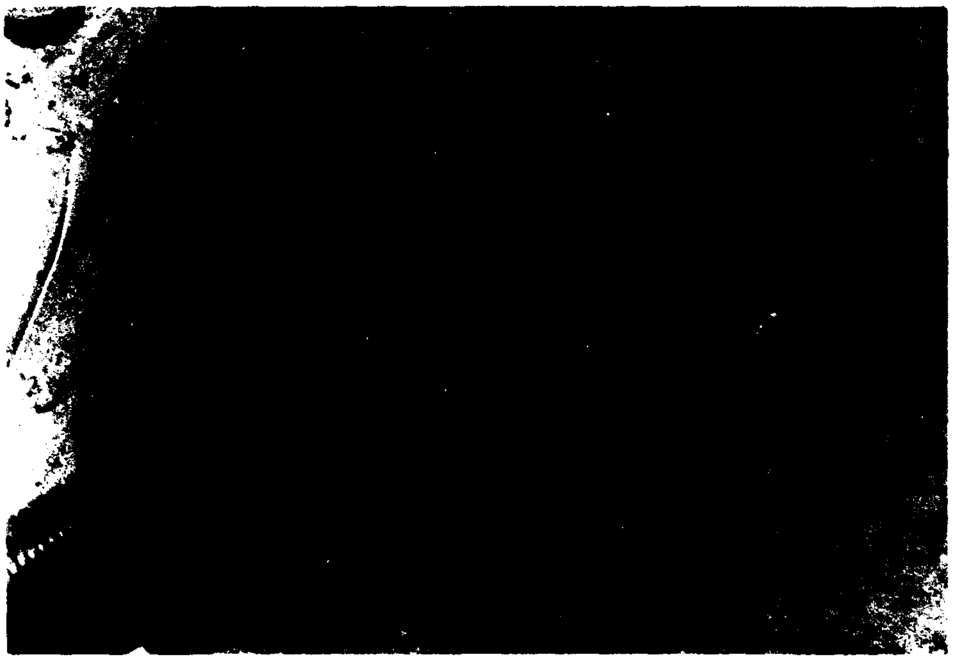
tensile capacities were essentially the same for comparable threaded-rod and reinforcing-bar anchors.

Shear Tests

30. Some bending of the anchors occurred during the shear tests (Figure 26) as a result of localized failure of the grout and concrete near the top of the holes. The extent of bending appeared to be influenced by the strength of the grout and the distance between the anchor and the edge of the drill hole. Although this bending probably caused some error in the test data, the results are considered to be a satisfactory estimate of the relative shear capacity of anchors installed under the various conditions.

31. Results of shear tests conducted at 2 days age on anchors installed in as-drilled holes (15-in. embedment) are shown in Figure 27. Shear loads at displacements of 0.2 and 0.4 in., in addition to the ultimate load, were selected as a basis for comparison of anchor performance under the various installation conditions. On this basis, results of the 2-day tests are summarized in the following:

a. Bending of anchor during test



b. Typical shear failure

Figure 26. Typical results of shear testing

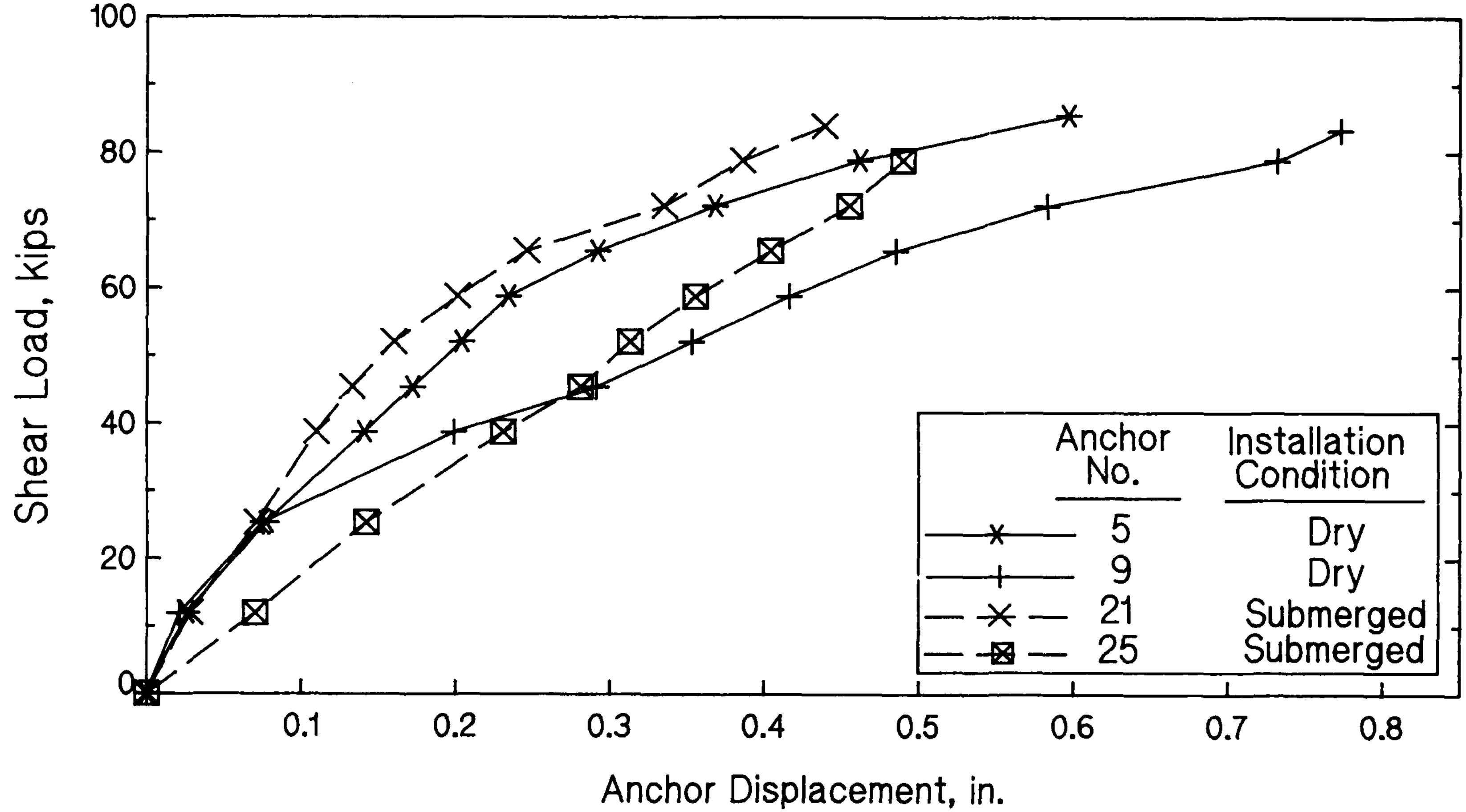


Figure 27. Results of shear tests conducted at 2 days age on anchors with 15-in. embedment lengths

Anchor No.	Installation Condition		Load, kips 0.2-in. Displ	0.4-in. Displ	Ultimate
5	Dry		51.3	74.5	85.6
9	Dry		38.8	57.1	83.3
		Avg	45.1	65.8	84.4
21	Submerged		58.6	80.2	84.0*
25	Submerged		34.1	64.9	78.9*
		Avg	46.4	72.6	81.4

* Test stopped prior to ultimate load.

At displacements of 0.2 and 0.4 in., the average shear load was slightly higher for anchors installed in as-drilled holes under submerged conditions compared with dry installation (Figure 28). If the anchors installed under submerged conditions had been loaded to failure, the ultimate shear capacity could have followed this trend. However, inadequate reaction beams in these initial shear tests necessitated stopping the tests at an average shear load slightly less than the ultimate for anchors installed in dry holes.

32. Results of shear tests conducted at 9 days age on anchors with 15-in. embedment lengths are shown in Figure 29 and summarized in the following:

Anchor No.	Installation Condition	Load, kips 0.2-in. Displ	0.4-in. Displ	Ultimate
8	Dry (flushed)	46.7	73.7	82.9
16	Dry (as-drilled)	34.8	58.4	82.9
20	Submerged (as-drilled)	38.8	52.7	78.6
28	Submerged (flushed)	47.2	66.8	77.0

Results of the limited number of tests suggest that partial cleaning of the drill holes by flushing with tap water had little effect on the ultimate shear capacity of anchors installed under either dry or submerged conditions. Where a direct comparison was possible, results indicate the shear capacity was essentially the same at 2 and 9 days age.

33. Results of shear tests conducted at 2 days age on anchors with 12-in. embedment lengths are shown in Figure 30 and summarized in the following:

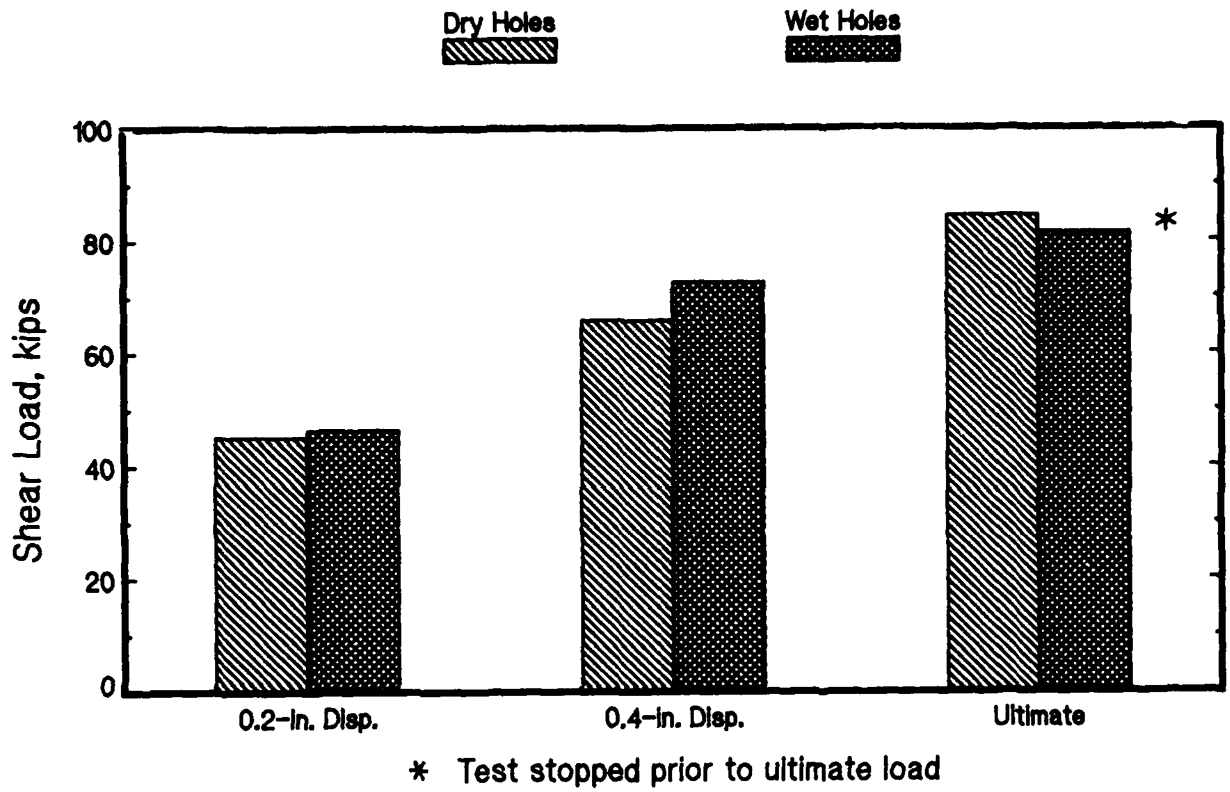


Figure 28. Summary of shear test results for anchors with 15-in. embedment lengths

Anchor No.	Installation Condition		Load, kips 0.2-in. Displ	0.4-in. Displ	Ultimate
40	Dry (flushed)		43.2	67.2	84.5
42	Dry (flushed)		45.3	67.7	81.5
43	Dry (flushed)		67.2	84.2	93.3
		Avg	51.9	73.0	86.4
45	Submerged (as-drilled)		31.8	53.2	73.5
47	Submerged (as-drilled)		29.5	56.7	80.7
49	Submerged (as-drilled)		31.3	56.4	82.1
		Avg	30.9	55.4	78.8

For a given shear load, the displacement of anchors installed in as-drilled holes under submerged conditions was significantly higher in comparison with anchors installed in dry holes that had been partially cleaned by flushing with tap water. Although no direct comparisons could be made, the average ultimate shear capacity was similar for anchors with either 12- or 15-in. embedment lengths.

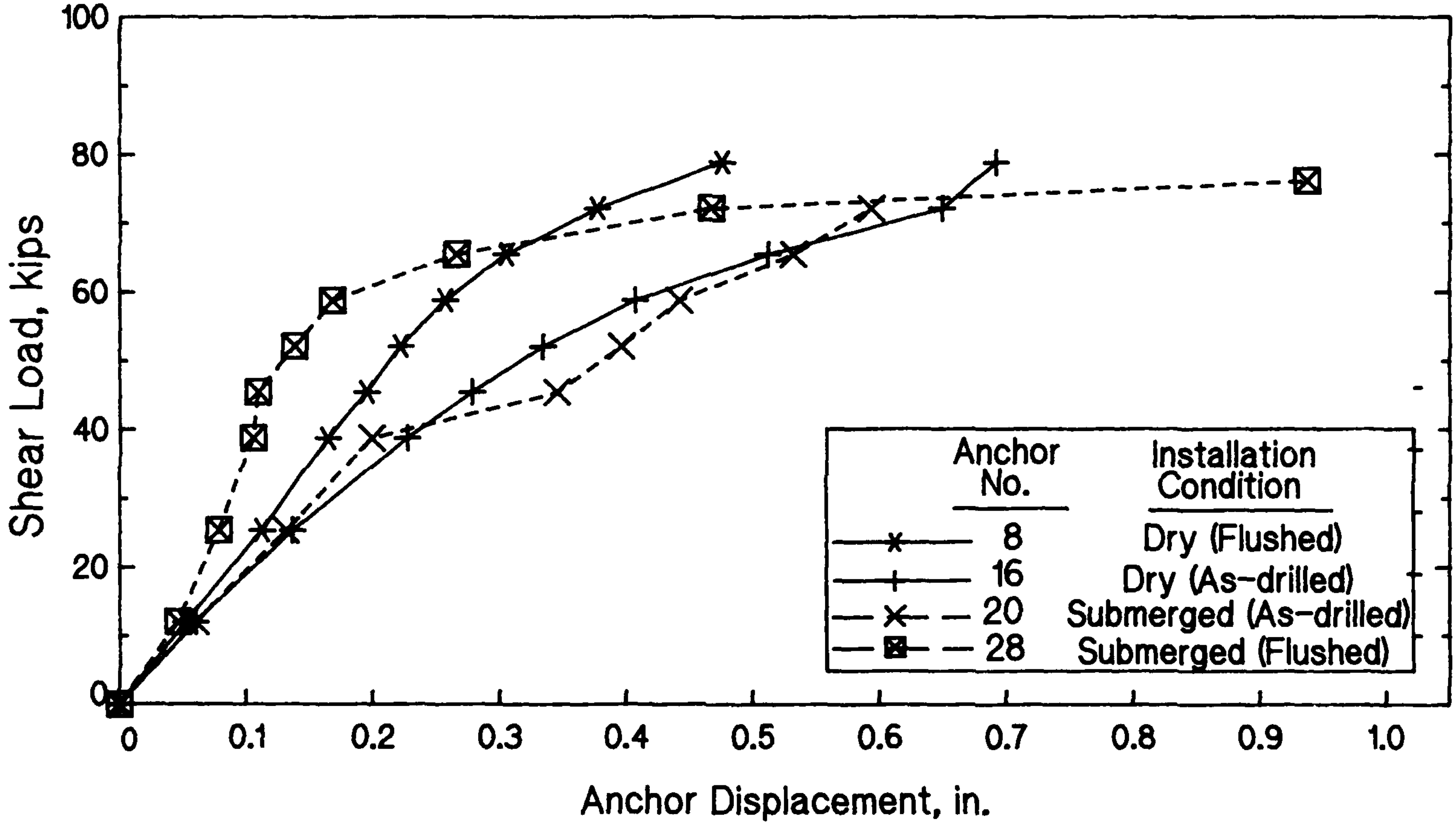


Figure 29. Results of shear tests conducted at 9 days age on anchors with 15-in. embedment lengths

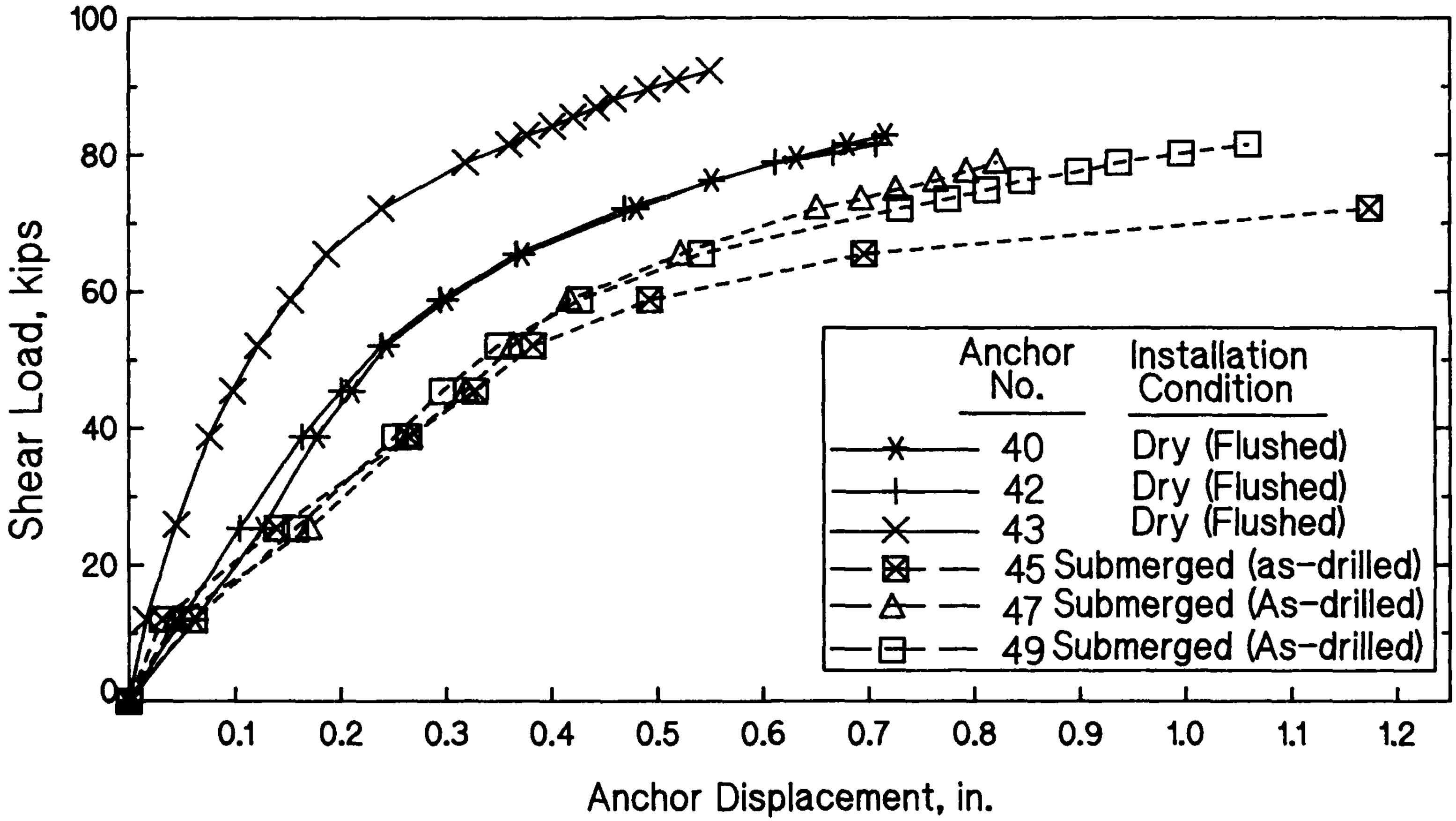


Figure 30. Results of shear tests conducted at 2 days age on anchors with 12-in. embedment lengths

34. Overall, ultimate shear capacities ranged from 73.5 to 93.3 kips with an average of 82.2 kips. Excluding the results of two tests, the upper and lower bound values, ultimate shear capacities ranged from 77.0 to 85.6 kips with an average of 81.9 kips. Accordingly, ultimate shear capacities were all within 10 percent of the average, regardless of embedment length, installation condition, and testing age. This result is attributed to the relatively small annulus present when a 1-1/4-in.-diam anchor is embedded in a hole drilled with a 1-1/2-in.-diam core drill. In essence, the test results reflect the shear capacity of the steel anchor with primary resistance being provided by the concrete with little, if any, contribution by the embedment material.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

35. For the range of parameters in this study (hole condition, embedment length, and test age), results of pullout tests on threaded-rod anchors installed in dry holes were remarkably consistent with an overall average tensile capacity of 105 kips at 0.1-in. displacement and an average ultimate load of approximately 125 kips which is near the yield load of the anchors. In comparison, results of pullout tests on anchors installed under submerged conditions were relatively erratic with an overall average tensile capacity of 36 kips at 0.1-in. displacement and an average ultimate load of 48 kips. Obviously, the tensile load capacity of anchors embedded in concrete with Hilti's HEA vinylester resin capsules is significantly reduced when the anchors are installed under submerged conditions. At a displacement of 0.1 in., the tensile capacity of anchors embedded under submerged conditions was approximately one-third that of similar anchors embedded in dry holes.

36. Cleaning the drill holes prior to anchor installation was unsuccessful in improving the performance of anchors installed under submerged conditions. The average tensile capacity of anchors installed in holes flushed with tap water was only 7 percent higher than that of anchors installed in as-drilled holes containing turbid water. Even additional cleaning of the holes with a bristle brush during the flushing process failed to improve anchor performance.

37. Reducing the anchor embedment length from 15 to 12 in. resulted in some reduction in tensile capacity. These reductions averaged slightly less than 5 and 15 percent for anchors installed under dry and submerged conditions, respectively.

38. Limited test results indicate that ultimate tensile capacities are essentially the same for comparable threaded-rod and reinforcing-bar anchors.

39. Excluding the results of two tests, the upper and lower bound test results, the ultimate shear capacities were all within 10 percent of the average regardless of embedment length, installation condition, and testing age. This result is attributed to the relatively small annulus present when a 1-1/4-in.-diam anchor is embedded in a hole drilled with a 1-1/2-in.-diam core drill. In essence, the test results reflect the shear capacity of the steel

anchor with primary resistance being provided by the concrete with little, if any, contribution by the embedment material.

Recommendations

Design of anchor systems

40. The significantly reduced tensile load capacity of anchors embedded in concrete with HEA vinylester resin capsules under submerged conditions should be recognized in any design of anchor systems for underwater applications. For the types of anchors and installation conditions described herein, a maximum tensile load of not more than 24 kips is recommended for design of underwater anchor systems subjected to short duration loads. This load was determined by reducing the overall average tensile capacity at 0.1-in. displacement by the standard deviation. Appropriate factors of safety should be used to calculate the maximum allowable tensile load.

41. Creep tests should be conducted to evaluate the effect of sustained loads on anchor performance prior to using HEA vinylester resin capsules for embedment of anchors that will be subjected to long-term loads.

Environmental considerations

42. Reasonable caution should guide the preparation, repair, and cleanup phases of concrete repair activities involving potentially hazardous and toxic chemical substances. Manufacturers' directions and recommendations for the protection of occupational health and environmental quality should be carefully followed. Material safety data sheets should be obtained from the manufacturers of such materials. In cases where the effects of a chemical substance on occupational health and environmental quality are unknown, chemical substances should be treated as potentially hazardous or toxic materials.

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McDonald, J. E., and Best, J. F. 1986. "Results from TVA Testing of Grouting Systems for Concrete Anchors," The REMR Bulletin, Vol 3, No. 3, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

US Army Engineer District, New Orleans. 1977. "Old River Low Sill Control Structure, Underwater Stilling Basin Inspection Report No. 1," New Orleans, La.

__________. 1986. "Old River Low Sill Control Structure, Underwater Stilling Basin Inspection Report No. 8," New Orleans, La.

APPENDIX A: MATERIAL SAFETY DATA SHEET

MSDS: 100 REVISION: 001
REVISION DATE: 05/26/88

MATERIAL SAFETY DATA SHEET

HILTI, INC.
5400 SOUTH 122ND EAST AVE.
TULSA, OKLAHOMA 74146

TELEPHONE: (918) 252 6000
INSIDE OKLAHOMA: (800) 722 3606
INSIDE CONTINENTAL U.S: (800) 331 3427

PRODUCT IDENTIFICATION

PRODUCT NAME: HEA

DESCRIPTION: VINYLESTER SYSTEM PACKED IN SEALED GLASS TUBES. PART A IS IN THE OUTER TUBE AND PART B IS IN THE INNER TUBE.

HAZARDOUS INGREDIENTS

INGREDIENTS:	%	CAS NUMBER:	EXPOSURE LIMITS:
PART A: STYRENE	--	00100-42-5	PEL: 100 PPM TLV: 50 PPM
VINYL ESTER RESIN	--	62395-94-2	NONE ESTABLISHED
PART B: DIBENZOYL PEROXIDE	--	00094-36-0	PEL: 5 MG/M3 TLV: 5 MG/M3
SILICON DIOXIDE	--	14808-60-7	PEL: 10 MG/M3 * TLV: 0.1 MG/M3 * * (AS RESPIRABLE DUST)

PEL = OSHA PERMISSABLE EXPOSURE LIMIT. TLV = ACGIH THRESHOLD LIMIT VALUE. THIS IS AN 8 HOUR TIME WEIGHTED AVERAGE UNLESS OTHERWISE INDICATED BY "C" (CEILING) OR "STEL" (SHORT TERM EXPOSURE LIMIT).

PHYSICAL DATA

APPEARANCE AND ODOR: PART A: LIGHT YELLOW VISCOUS LIQUID, STYRENE ODOR.
PART B: GRAY GRAVEL-LIKE MATERIAL.

BOILING POINT: PART A: 248-282 F
PART B: DECOMPOSES @ 150 F

MELTING POINT: NOT DETERMINED

VAPOR PRESSURE: 6MM HG @ 68 F (STYRENE)

VAPOR DENSITY: 3.6 (STYRENE)

EVAPORATION RATE: NOT DETERMINED

SOLUBILITY IN WATER: NIL

SPECIFIC GRAVITY: PART A: 1.07
PART B: 2.61

PH: NOT DETERMINED

FIRE AND EXPLOSION HAZARD DATA

FLASH POINT: 93 F (TCC)

FLAMMABLE LIMITS: LEL = 1.1 UEL = 6.1

EXTINGUISHING MEDIA: CARBON DIOXIDE, DRY CHEMICAL, FOAM, WATER

SPECIAL FIRE FIGHTING PROCEDURES: COOL WITH WATER SPRAY. USE SELF-CONTAINED BREATHING APPARATUS.

UNUSUAL FIRE AND EXPLOSION HAZARDS: ISOLATE FROM HEAT, ELECTRICAL EQUIPMENT, SPARKS, AND OPEN FLAME. DECOMPOSITION AND COMBUSTION PRODUCTS MAY BE TOXIC. GLASS TUBES MAY EXPLODE WHEN EXPOSED TO EXTREME HEAT.

REACTIVITY DATA

STABILITY: STABLE AT TEMPERATURES BELOW 122 F.

CONDITIONS TO AVOID: OPEN FLAMES OR SPARKS. STORAGE ABOVE 100 F.

INCOMPATABILITY: STRONG ACIDS, PEROXIDES, AND OTHER OXIDIZING AGENTS.

HAZARDOUS DECOMPOSITION PRODUCTS: CARBON DIOXIDE, CARBON MONOXIDE.

HAZARDOUS POLYMERIZATION: WILL NOT OCCUR. CONDITIONS TO AVOID: STYRENE WILL POLYMERIZE AT ELEVATED TEMPERATURES. BENZOYL PEROXIDE WILL DECOMPOSE AT TEMPERATURES > 150F.

----------------------------- HEALTH HAZARD DATA -----------------------------

CARCINOGENICITY: CRYSTALINE SILICA IS CONSIDERED BY IARC TO BE AN ANIMAL CARCINOGEN. THE NATURE & USE OF THIS PRODUCT SHOULD NOT POSE A CANCER RISK TO HUMANS.

PRIMARY ROUTES OF EXPOSURE: DERMAL, INHALATION.

SIGNS AND SYMPTOMS OF EXPOSURE: CAUSES EYE BURNS. SKIN IRRITANT. CAN HAVE A NARCOTIC EFFECT IF INHALED. CAN CAUSE ALLERGIC SKIN AND RESPIRATORY CONDITIONS. "STYRENE SICKNESS" CONSISTING OF DROWSINESS, NAUSEA, HEADACHE, FATIGUE, AND DIZZINESS HAS BEEN MENTIONED IN WORKERS EXPOSED AT 200-700 PPM.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: SKIN AND EYE CONDITIONS.

------------------------ EMERGENCY AND FIRST AID PROCEDURES ------------------

EYES: IMMEDIATELY FLUSH WITH PLENTY OF WATER FOR AT LEAST 15 MINUTES. CALL A PHYSICIAN.

SKIN: WASH WITH SOAP AND WATER. REMOVE CONTAMINATED CLOTHING AND LAUNDER BEFORE REUSE.

INHALATION: MOVE VICTIM TO FRESH AIR. GIVE OXYGEN AND/OR ARTIFICIAL RESPIRATION IF NEEDED. CALL A PHYSICIAN.

INGESTION: GIVE PLENTY OF WATER TO DRINK. DO NOT INDUCE VOMITING. CALL A PHYSICIAN. NEVER GIVE ANYTHING BY MOUTH TO AN UNCONSCIOUS PERSON.

OTHER: REFERRAL TO A PHYSICIAN IS RECOMMENDED IF THERE IS ANY QUESTION ABOUT THE SERIOUSNESS OF THE INJURY/EXPOSURE.

----------------- CONTROL MEASURES AND PERSONAL PROTECTIVE EQUIPMENT ----------

VENTILATION: GENERAL (NATURAL OR MECHANICALLY INDUCED FRESH AIR MOVEMENTS THAT MAINTAIN VAPOR CONCENTRATIONS BELOW RECOMMENDED EXPOSURE LIMITS).

EYE PROTECTION: SAFETY GLASSES (SIDE SHIELDS RECOMMENDED).

PROTECTIVE GLOVES: IMPERMEABLE (NEOPRENE OR RUBBER).

RESPIRATORY PROTECTION: USE NIOSH APPROVED ORGANIC VAPOR RESPIRATOR WHEN VAPOR CONCENTRATIONS EXCEED RECOMMENDED EXPOSURE LIMITS.

----------------------- PRECAUTIONS FOR SAFE HANDLING AND USE -----------------

PRECAUTIONARY LABELING: WARNING: FLAMMABLE. CAUSES EYE BURNS AND SKIN IRRITATION. CAN HAVE AN ANESTHETIC EFFECT IF INHALED. CAN CAUSE ALLERGIC SKIN AND RESPIRATORY REACTIONS.

KEEP AWAY FROM HEAT SPARKS AND OPEN FLAME. AVOID CONTACT WITH EYES, SKIN AND CLOTHING. AVOID BREATHING VAPOR. AVOID PROLONGED OR REPEATED CONTACT WITH SKIN. USE WITH ADEQUATE VENTILATION. WASH THOROUGHLY AFTER HANDLING.

HANDLING AND STORING: KEEP IN A COOL DRY PLACE OUT OF DIRECT RAYS OF SUN. STORE BELOW 100 F. KEEP AWAY FROM IGNITION SOURCES SUCH AS EXCESS HEAT, SPARKS, AND OPEN FLAME.

SPILL PROCEDURES: REMOVE ALL SOURCES OF IGNITION. COVER WITH ABSORBENT MATERIAL AND PLACE IN SALVAGE CONTAINER FOR PROPER DISPOSAL.

REGULATORY INFORMATION

OSHA HAZARD COMMUNICATION: THIS MATERIAL SAFETY DATA SHEET HAS BEEN PREPARED IN COMPLIANCE WITH THE FEDERAL OSHA HAZARD COMMUNICATION STANDARD AND THIS PRODUCT IS CONSIDERED TO BE A HAZARDOUS CHEMICAL UNDER THAT STANDARD.

DOT PROPER SHIPPING NAME: RESIN SOLUTION/FLAMMABLE LIQUID/UN 1866.

TSCA INVENTORY STATUS: CHEMICAL COMPONENTS LISTED ON TSCA INVENTORY.

WASTE DISPOSAL METHODS: CONSULT WITH REGULATORY AGENCIES OR CORPORATE PERSONNEL FOR DISPOSAL METHODS THAT COMPLY WITH LOCAL, STATE, AND FEDERAL HEALTH AND ENVIRONMENTAL REGULATIONS.

CONTACTS:

TECHNICAL: BERT MAYER
HEALTH/SAFETY: STEVE GERRARD

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